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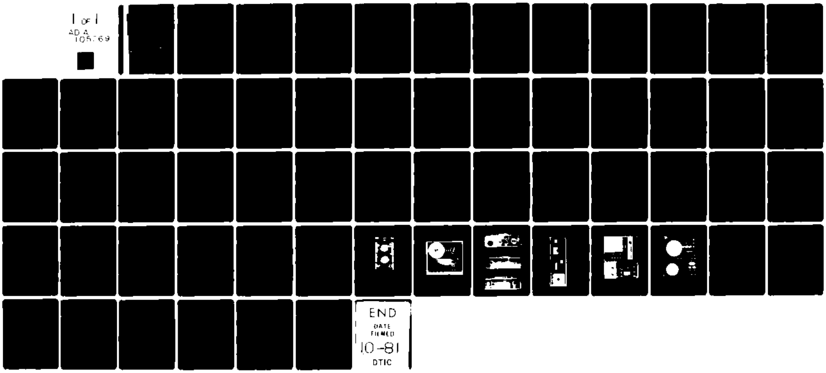

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Mechanical Engineering Technical Memorandum 408

VIBRATION TEST PROCEDURES FOR ACCESSORY ANGLE DRIVE GEARBOXES ON ATAR 09C ENGINES

P.D. McFADDEN and D.H. EDWARDS

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P.D. McFADDEN and D.M. EDWARDS

SUMMARY

The Accessory Angle Drive gearbox powers the fuel and hydraulic pumps on the Atar engine in the Mirage aircraft. To insure against in-flight failure, each gearbox is vibration tested under load after overhaul by the local contractor.

A new vibration testing technique, offering greatly improved accuracy and reliability, has been developed. The technique uses a real-time, fast-fourier spectrum analyzer, with direct digital read-out in engineering units, and a tracking adapter with built-in anti-aliasing filter.

This report defines correct procedures for the connection and operation of the instruments, and the interpretation of the results.

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16. ABSTRACT:

The Accessory Angle Drive gearbox powers the fuel and hydraulic pumps on the Atar engine in the Mirage aircraft. To insure against in-flight failure, each gearbox is vibration tested under load after overhaul by the local contractor.

A new vibration testing technique, offering greatly improved accuracy and reliability, has been developed. The technique uses a real-time, fast-fourier spectrum analyzer, with direct digital read-out in engineering units, and a tracking adapter with built-in anti-aliasing filter.

This report defines correct procedures for the connection and operation of the instruments, and the interpretation of the results.

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1. INTRODUCTION

Between 1968 and 1970, the French Air Force lost three Mirage aircraft because of fatigue failures in the teeth of the Coniflex type driven bevel gear in the accessory angle drive gearboxes of their Atar engines, and a further two gears were found to be cracked at overhaul. At that time, the Coniflex gears were being replaced by gears with a Zerol tooth form and a mixture of both types was in service. SNECMA, the engine manufacturer, placed a severe limitation on the allowable operating life of both types of gear and commenced an investigation into the cause of failures.

Initial findings suggested that at certain speeds the normal gear meshing loads could excite a resonant mode in the gear. SNECMA proposed a redesigned Zerol gear with a thicker web and introduced a method of assessing gearbox condition by measuring vibration levels at the gear meshing frequencies.

Although the Royal Australian Air Force (RAAF) had not experienced any failures of the gears in the Atar 09C engines in its Mirage fleet, it was anxious to avoid similar problems pending the introduction of the redesigned gears. The Aeronautical Research Laboratories (ARL) were requested to develop techniques of vibration measurement similar to those proposed by SNECMA and to conduct a survey of all the angle drive gearboxes in the RAAF fleet, with a view to withdrawing from service those boxes with high or abnormal vibration. This task, performed by the Mechanical Engineering Division of ARL, is described in Reference 1.

In 1972, SNECMA introduced an instrument called the Elecma Tracking Filter, designed to simplify the analysis of the angle drive gearbox vibration during inspection. It consisted of a bank of narrow-band tracking filters, tuned to the gear meshing frequencies by a suitable tachogenerator signal, and presenting the amplitude of each vibration component on an analogue meter. The RAAF ordered one of these instruments for use by the Commonwealth Aircraft Corporation (CAC) in the overhaul of the Atar engines. The Elecma was used successfully by CAC for a number of years, but after increases in the downtime for repair and recalibration, ARL were asked to recommend an alternative method of analysis.

ARL proposed a method requiring new accelerometers, a matching amplifier, a real-time narrow-band spectrum analyzer and a tracking adapter with anti-aliasing filter. These instruments were acquired by CAC in 1978. A portable tape recorder was also purchased to enable recordings of gearbox vibration to be made in different test houses and analyzed at one central location.

This report has been prepared as a guide to the correct operation of the instruments and the interpretation of the results.

2. DESCRIPTION OF THE INSTRUMENTS

2.1 Overview

Figure 1 shows a schematic diagram of the instruments used for the vibration testing of the angle drive gearbox. An accelerometer bolted to the gearbox casing converts the vibration into an electrical signal which is amplified and then passed through an attenuator to one channel of a tape recorder. The signal from one phase of the engine tachogenerator is passed through an isolating transformer to the other channel of the tape recorder. In this manner, signals representing the vibration and speed of the gearbox may be recorded simultaneously.

When the tape is reproduced, the tachogenerator signal controls the sampling rate of the spectrum analyzer and the cut-off frequency of the anti-aliasing filter. The vibration signal is passed through this filter to the spectrum analyzer, where its component frequencies are displayed. Entering the appropriate scaling factor into the spectrum analyzer allows the direct digital read-out in engineering units of each vibration component.

Since the sampling rate of the spectrum analyzer is proportional to the frequency of the tachogenerator signal, the spectrum will be displayed as a function of engine orders instead of absolute frequency. Although the engine speed will change during the test, the position of each vibration component will remain fixed on the display.

With the spectrum analyzer in the peak mode, the memory contents at the end of a vibration test will show the highest vibration level reached by each component during the test. By comparing the magnitude of each component with a table of maximum permissible vibration levels, the condition of the gearbox may be assessed.

The use of the tape recorder is optional. On-line analysis may be performed with equal ease and greater accuracy; therefore it is recommended that on-line analysis be performed whenever possible.

Further details of each of the instruments are given in the following sections.

2.2 Accelerometer

The Kistler 815A2 Piezotron Accelerometer is a hermetically sealed quartz transducer containing an integral impedance converter which provides a low-impedance output enabling conventional shielded cable to be used without degradation of performance.

The accelerometer may be mounted on any flat surface normal to the required measurement axis using a threaded stud in a tapped hole. Adhesive mounting is not recommended, as tests by ARL have shown that the high frequency response is degraded by this method.

The accelerometer mounting procedures are described in Sections 4.4 and 5.1. Full performance data are contained in Reference 2.

2.3 Amplifier

The Kistler 504E Dual Mode Amplifier is suitable for use with either straight piezoelectric transducers or transducers containing an integral impedance converter.

A transducer sensitivity control on the amplifier enables the amplifier output to be set to integer values of engineering units per volt as selected by the amplifier range control, regardless of the sensitivity of the transducer.

Power for the impedance converter in the transducer is provided by the amplifier via the connecting cable. Plug-in low-pass filters may be selected in order to reduce the effect of the transducer resonance and attenuate unwanted noise.

Full specifications are provided in Reference 3.

2.4 Attenuator

The RECORD LEVEL controls on the tape recorder do not have detents and can only be set repeatably in the MIN and MAX sensitivity settings. Unfortunately the optimum sensitivity setting required to match the amplifier and tape recorder lies between these two extremes. To obtain repeatable attenuation of the vibration signal, a simple, frequency-compensated attenuator has been supplied by ARL. When the RECORD LEVEL control is set to the MAX position and the attenuator inserted in the connection between the amplifier and the tape recorder, the correct attenuation is produced. The attenuator is housed in a small aluminium tube and may be connected either way around without impairing the high-frequency performance of the tape recorder.

2.5 Isolating Transformer

During testing, the engine tachogenerator signal is used to drive the test-house tachometer. To avoid ground loop noise problems the tachometer signal ground is isolated from the tape recorder input ground by a transformer. The signal produced by the tachogenerator is in excess of 60 mV RMS and contains a very large component at the frequency of the tenth harmonic of the tachogenerator shaft speed. Before this signal can be recorded or used to control the tracking adapter, it must be isolated, attenuated and filtered.

A simple isolating transformer, with a built-in attenuator and bandpass filter, has been supplied by ARL.

2.6 Tape Recorder

The Sony Stereo Tapecorder TC-510-2 is a moderately-priced, direct-recording, two-channel, portable, reel-to-reel tape recorder. Although intended primarily for audio recording, the performance specifications given by the manufacturer indicate it may be suitable for many vibration recording applications. Full details of the specifications are given in Reference 4.

The performance of the unit acquired by CAC has not been as good as the specifications would suggest. Measurements made according to the procedure described in Appendix C have shown that the frequency response for channel L is inadequate for recording the vibration signal without some corrective action. By operating the amplifier with the 150 kHz filter inserted, the rising response characteristic of the accelerometer will tend to compensate for the fall in response of the tape recorder. In this manner, adequate performance can be obtained.

Further measurements, made according to the procedure described in Appendix C have shown that the frequency response of channel R is inferior to that of channel L. Fortunately, the recording of the tachogenerator signal does not require high fidelity, and so channel R is adequate for that purpose.

In view of the poor frequency response of the tape recorder and the need for frequent recalibration, it is recommended that on-line analysis be performed whenever possible.

2.7 Tracking Adapter and Spectrum Analyzer

The Nicolet 444A Mini-Ubiquitous FFT Computer Spectrum Analyzer is a real-time, narrow-band fast fourier analyzer with resolution of 400 lines. It features 16 frequency analysis ranges, transient capture capability, linear or logarithmic display of frequency and amplitude axes, full display annotation, and a dual memory with the ability to display the sum, difference and ratio of the memory contents. Full specifications are provided in Reference 5.

The instrument purchased by CAC is fitted with Option 05, comprising a set of built-in testing routines which enable the performance of the digital circuits to be checked in the field.

The Nicolet 24C Spectrum Tracking Adapter accepts a reference frequency generated by the machine of interest and converts it to a frequency suitable for controlling the sampling rate of the 444A Spectrum Analyzer. Changes in the speed of the machine therefore

cause proportional changes in the sampling frequency with the result that the components of the spectrum remain in a fixed position independent of the speed of the machine. The sampling rate control greatly facilitates the monitoring of machines which do not run at constant speed.

The tracking adapter purchased by CAC is fitted with Option 07, comprising a low-pass tracking filter which automatically adjusts its cut-off frequency according to the sampling frequency. The signal to be analyzed is first passed through the filter, which blocks frequencies above the current analyzer range thereby preventing aliasing errors.

Full specifications are provided in Reference 6.

3. SPECIAL PRECAUTIONS

3.1 General

1) Extreme care must be exercised when setting the controls on the instruments, since even one incorrect setting may cause erroneous results.

2) The frequency response of the system for on-line analysis is superior to that for recording and off-line analysis. Therefore it is recommended that on-line analysis be performed whenever possible.

3.2 Accelerometer and Amplifier

1) Dropping an accelerometer may expose it to shocks of several thousand g, and may produce a signal of sufficient amplitude to destroy the integral impedance converter. Should an accelerometer be dropped, it should not be used before a recalibration has been performed.

2) The input stage of the amplifier contains a field-effect transistor which may be easily damaged by stray voltages which accumulate on the accelerometer cable For this reason, the procedures described in Sections 4.5 and 5.2 should be followed carefully each time the accelerometer, cable and amplifier are to be connected.

3) When using the amplifier in the piezotron mode, the charge input must be protected with the metal shielding cap connected (via the integral chain) to the rear panel of the amplifier.

4) When used for on-line analysis as described in Section 5, the specially matched 20 kHz filter MUST be inserted in the socket on the rear panel of the amplifier. This ensures that the frequency response of the system is flat over the required range.

5) When data are to be recorded on magnetic tape as described in Section 4, the 150 kHz filter MUST be inserted in the socket on the rear panel of the amplifier. The rising response characteristic of the unfiltered accelerometer compensates for the fall in response of the tape recorder, giving a frequency response for the system that is approximately flat over the required range.

3.3 Tape Recorder

1) Before mounting each tape, the head, guide and capstan surfaces should be cleaned with a cotton swab slightly moistened with a recommended cleaning solution or Freon TF.

2) Unnecessary handling of the tape surfaces should be avoided when loading and unloading. The tapes should be stored in a clean, dry environment.

3) The dust-proof cover should be closed except when cleaning, loading or unloading the tape, or adjusting the controls.

4) Channel L of the recorder has better frequency response characteristics than channel R. Only channel L should be used for the recording of reference and vibration signals. Channel R is adequate for recording the tachogenerator signal.

5) When recordings are to be made, the outer RECORD LEVEL control (channel L) MUST be turned FULLY CLOCKWISE to the MAX position and the supplied attenuator inserted in the input lead to channel L. This procedure ensures that the attenuation will remain the same for all recordings.

6) The Reproduce Ratio of a magnetic tape is defined as the ratio of the level of a reference signal appearing at the output of the reproducing amplifier to that coupled to the input of the recording amplifier at the time of recording. The Reproduce Ratio of magnetic tapes will vary between tapes supplied by different manufacturers, and even among different tapes supplied by the one manufacturer. A reference signal MUST be recorded at the start of each tape, as described in Section 4.2, so that the Reproduce Ratio may be accurately determined for that specific tape.

7) The signal recorded on a tape may deteriorate over a long period of time. If an old recording is to be analyzed, the Reproduce Ratio for that tape should be recalculated by measuring the level of the reference signal as described in Section 4.3. If a new recording is to be made on a tape which has not been used for a long time, a new reference signal should also be recorded.

8) Residual magnetism will gradually accumulate on the heads after extensive use, causing an increase in tape noise and erasure of the higher frequency signals. After every 20 to 30 hours of operation, the heads and metallic parts of the tape path should be demagnetized with a head demagnetizer as shown in Reference 4. It is essential that the tape recorder be switched off before demagnetizing the above components.

3.4 Tracking Adapter

1) Since the engine tachogenerator signal used to trigger the adapter operates at 1.00728 times engine speed, the speed displayed on the tracking adapter will be approximately 0.7% higher than the true speed shown on the test house tachometer.

2) On the settings specified, the tracking adapter will take approximately 10 seconds to lock onto the tachogenerator signal. When recording a vibration signal for subsequent analysis, the engine speed should be held constant for the first 10 seconds of the recording.

3.5 Spectrum Analyzer

1) If certain of the front panel controls of the spectrum analyzer are operated in an abnormal sequence, the internal microprocessor may latch-up, causing the display to disappear. Normal operation may be restored by pressing the reset button on the rear panel of the analyzer.

2) The reference level of the analyzer is altered by turning the power off or depressing the CURSOR AMPLITUDE REFERENCE switch into the SET R position. It is essential that the reference level be set correctly before the amplitudes of the vibration peaks are measured.

3) Analyses should only be made with the ANNOTATION switch in the DATA position and the CURSOR FREQUENCY TYPE switch set to OFF. These settings minimize the time that the internal microprocessor spends on the presentation of the display, thereby enabling more complete analysis of the incoming data. Maximizing the analysis time is important for the testing of accelerating machines which may exhibit large transient resonances.

4. RECORDING AND OFF-LINE ANALYSIS

4.1 Loading the Tape Recorder

1) Clean the head, guide and capstan surfaces with a cotton swab slightly moistened with a recommended cleaning solution or Freon TF.

2) Mount the reel of tape on the left-hand reel holder and thread the tape as shown in Figure 9a.

3) Set the BIAS and EQUALIZATION controls to the positions shown in Table 1 according to the type of tape being used.

4) Press the tape counter RESET button.

4.2 <u>Recording a Reference Signal</u>

1) Connect a signal generator, voltmeter, attenuator and tape recorder as shown in Figure 2.

2) Depress the L and R RECORD MODE buttons.

3) Set the SOURCE/TAPE select switch to SOURCE.

4) Set the other controls of the tape recorder as shown in Figures 9a to 9d and Table 4.

5) Use the REWIND/FAST-FORWARD lever to move the tape to the required location as shown by the tape counter.

6) Log the reading of the tape counter on the Record Sheet.

7) Adjust the signal generator output frequency to approximately 2 kHz.

8) Adjust the signal generator output level until the voltmeter indicates approximately 1 V RMS.

9) Log the exact reading of the voltmeter on the Record Sheet.

10) Push the FUNCTION selector and turn it clockwise to the RECORD position.

11) Change the SOURCE/TAPE select switch to TAPE. The sound from the monitor speaker should be clear and undistorted.

12) After approximately 60 seconds, turn the FUNCTION selector counter-clockwise to the STOP position.

13) Log the reading of the tape counter on the Record Sheet.

14) Release the L and R RECORD MODE buttons.

4.3 Reproducing a Reference Signal

1) Connect the tape recorder and voltmeter as shown in Figure 3.

2) Release the L and R RECORD MODE buttons.

3) Set the SOURCE/TAPE select switch to TAPE.

4) Set the other controls of the tape recorder as shown in Figures 9a to 9d and Table 4.

5) Use the REWIND/FAST-FORWARD lever to move the tape to the start of the recorded reference signal as shown by the tape counter.

6) Turn the FUNCTION selector counter-clockwise to the PLAYBACK position.

7) Log the reading of the voltmeter on the Record Sheet.

8) Turn the FUNCTION selector clockwise to the STOP position.

9) Calculate the Reproduce Ratio for the tape from the following equation:

$$\text{Reproduce Ratio} = \frac{\text{reference signal on playback (V RMS)}}{\text{recorded reference signal (V RMS)}} \qquad (1)$$

10) Log the Reproduce Ratio on the Record Sheet.

4.4 Mounting the Accelerometer

1) Disconnect the accelerometer cable from the amplifier.

2) Smear the modified angle drive retaining bolt face and washer with a light silicone grease, then fit these to the lower centre mounting hole.

3) Smear the base of the accelerometer with a light silicone grease.

4) Screw the accelerometer onto the mounting stud, checking that the stud does not bottom in the accelerometer housing.

5) Tighten the accelerometer to a torque of 2±.2 Nm (18±2 lbf in).

6) Examine the connectors on the accelerometer and the cable for contaminants, and clean with Freon TF if necessary.

7) Connect the cable to the accelerometer.

8) Tape the cable to the body of the accelerometer to strain relieve the connector.

4.5 Connecting the Accelerometer to the Amplifier

1) Insert the 150 kHz filter in the socket on the rear panel of the amplifier.

2) Set the operating mode switch on the amplifier to the PIEZOTRON position.

3) Set the OPERATE/GROUND switch to the GROUND position.

4) Turn the amplifier power on.

5) Wait 10 minutes for the amplifier to warm up.

6) Set the RANGE switch to the 5K position.

7) Connect the accelerometer cable to the PIEZOTRON input of the amplifier as shown in Figure 4.

8) Set the TRANSDUCER SENSITIVITY control to the value shown in Table 2 for the transducer used.

4.6 Recording a Vibration Signal

1) Connect the accelerometer, amplifier, attenuator, isolating transformer and tape recorder as shown in Figure 5.

2) Set the amplifier controls as shown in Figure 8 and Table 3.

3) Depress the L and R RECORD MODE buttons.

4) Set the SOURCE/TAPE select switch to SOURCE.

5) Set the other controls of the tape recorder as shown in Figures 9a to 9d and Table 4.

6) Use the REWIND/FAST-FORWARD lever to move the tape to the required location as shown by the tape counter.

7) Log the reading of the tape counter on the Record Sheet.

8) Adjust the amplifier RANGE setting until the left-hand VU meter indicates less than 100% on the lower scale, allowing sufficient over-range for the expected maximum vibration level during the test.

9) Log the amplifier range on the Record Sheet.

10) Adjust the inner RECORD LEVEL control (Channel R) until the right-hand VU meter indicates less than 100% on the lower scale.

11) Warm up the engine and set the speed to 5800 RPM.

12) Push the FUNCTION selector and turn it clockwise to the RECORD position.

13) Maintain the speed constant for approximately 15 seconds, then slowly accelerate the engine.

14) Observe the left-hand VU meter. If the needle moves repeatedly into the red zone the test should be repeated beginning at step 9 with the amplifier set on a higher RANGE scale.

15) When the engine speed reaches 8400 RPM, maintain this speed for approximately two minutes.

16) Accelerate the engine to the overspeed condition of 8650 RPM.

17) After approximately 10 seconds, turn the FUNCTION selector counter-clockwise to the STOP position.

18) Shut down the engine.

19) Log the reading of the tape counter on the Record Sheet.

20) Release the L and R RECORD MODE buttons.

21) Change the OPERATE/GROUND switch on the amplifier to GROUND.

4.7 <u>Analyzing a Vibration Recording</u>

1) Connect the tape recorder, tracking adapter and spectrum analyzer as shown in Figure 6.

2) Release the L and R RECORD MODE buttons.

3) Set the SOURCE/TAPE select switch to TAPE.

4) Set the other controls of the tape recorder as shown in Figures 9a to 9d and Table 4.

5) Use the REWIND/FAST-FORWARD lever to move the tape to the start of the recorded vibration signal as shown by the tape counter.

6) Set the SIGNAL ATTENUATOR on the tracking adapter to 10 dB.

7) Set the other controls on the tracking adapter as shown in Figure 10 and Table 5.

8) Set the CURSOR FREQUENCY TYPE switch on the spectrum analyzer to OFF.

9) Set the other controls of the spectrum analyzer as shown in Figures 11a and 11b and Table 6.

10) Turn the FUNCTION selector counter-clockwise to the PLAYBACK position.

11) Wait until the LOCK indication on the tracking adapter becomes steady, then press the START A button on the spectrum analyzer.

12) Observe the OVERLOAD indicators on the tracking adapter and the spectrum analyzer and the LOCK indicator on the tracking adapter. If either of the OVERLOAD indicators lights repeatedly, or if the LOCK indicator extinguishes at any time, check all connections and control settings and repeat the test beginning at step 10.

13) Observe the tape counter and press the STOP A button on the spectrum analyzer before the tape counter reaches the end of the recording.

14) Turn the FUNCTION selector clockwise to the STOP position.

15) Obtain the System Sensitivity setting for the amplifier RANGE scale used from Table 7.

16) Calculate the Corrected System Sensitivity from the following equation:

$$\text{Corrected System Sensitivity} = \text{Reproduce Ratio} \times \text{System Sensitivity} \qquad (2)$$

17) Change the CURSOR FREQUENCY TYPE switch on the spectrum analyzer to SINGLE.

18) Depress and HOLD the CURSOR AMPLITUDE REFERENCE switch on the spectrum analyzer in the SET R position, and raise or lower the GAIN switch until the value indicated in the REFERENCE LEVEL field of the display, shown in Figure 12, equals the Corrected System Sensitivity.

19) Depress or raise the GAIN control on the spectrum analyzer until the highest peak of the spectrum is close to but does not exceed the top grid line.

20) Press the CURSOR control to the left or right until the CURSOR POSITION field in the display as shown in Figure 12 indicates the percentage of full-scale orders for the first spectral component shown in Table 9.

21) Adjust the CURSOR control in single steps to the left or right until the cursor dot is at the peak of the nearest spectral component.

22) Read the CURSOR AMPLITUDE field of the display shown in Figure 12 and log it on the Record Sheet.

23) Repeat steps 20, 21 and 22 for all of the components shown in Table 9.

24) If all the measured amplitudes are less than the corresponding maximum permissible amplitudes shown in Table 9, the gearbox may be passed and testing is complete. If the 75.4 N component exceeds 40 g, but is less than 50 g, the following additional steps are necessary to determine whether the gearbox may be passed.

25) Use the REWIND/FAST-FORWARD lever to move the tape to the start of the recorded vibration signal as shown by the tape counter.

26) Turn the FUNCTION selector counter-clockwise to the PLAYBACK position.

27) Wait until the LOCK indication on the tracking adapter becomes steady and the SPEED indicator shows 7200 RPM, then press the START A button on the spectrum analyzer.

28) Repeat steps 12 to 23.

29) If the amplitude of the 75.4 N component is less than 40 g, the gearbox may be passed and testing is complete.

5. ON-LINE ANALYSIS

5.1 Mounting the Accelerometer

1) Disconnect the accelerometer cable from the amplifier.

2) Smear the modified angle drive retaining bolt face and washer with a light silicone grease then fit these to the lower centre mounting hole.

3) Smear the base of the accelerometer with a light silicone grease.

4) Screw the accelerometer onto the mounting stud, checking that the stud does not bottom in the accelerometer housing.

5) Tighten the accelerometer to a torque of 2±.2 Nm (18±2 lbf in).

6) Examine the connectors on the accelerometer and the cable for contaminants, and clean with Freon TF if necessary.

7) Connect the cable to the accelerometer.

8) Tape the cable to the body of the accelerometer to strain relieve the connector.

5.2 Connecting the Accelerometer to the Amplifier

1) Insert the 20 kHz filter in the socket on the rear panel of the amplifier.

2) Set the operating mode switch on the amplifier to the PIEZOTRON position.

3) Set the OPERATE/GROUND switch to the GROUND position.

4) Turn the amplifier power on.

5) Wait 10 minutes for the amplifier to warm up.

6) Set the RANGE switch to the 5K position.

7) Connect the accelerometer cable to the PIEZOTRON input of the amplifier as shown in Figure 4.

8) Set the TRANSDUCER SENSITIVITY to the value shown in Table 2 for the transducer used.

5.3 Analyzing a Vibration Signal On-Line

1) Connect the amplifier, voltmeter, isolating transformer, tracking adapter and spectrum analyzer as shown in Figure 7.

2) Set the amplifier controls as shown in Figure 8 and Table 3.

3) Set the SIGNAL ATTENUATOR on the tracking adapter to 15 dB.

4) Set the other controls on the tracking adapter as shown in Figure 10 and Table 5.

5) Set the CURSOR FREQUENCY TYPE switch on the spectrum analyzer to OFF.

6) Set the other controls of the spectrum analyzer as shown in Figures 11a and 11b and Table 6.

7) Adjust the amplifier RANGE scale setting until the voltmeter indicates less than 1 V RMS, allowing sufficient over-range for the expected maximum vibration level during the test.

8) Log the amplifier RANGE on the Record Sheet.

9) Warm up the engine and set the speed to 5800 RPM.

10) Wait until the LOCK indication on the tracking adapter becomes steady.

11) Press the START A button on the spectrum analyzer.

12) Slowly accelerate the engine.

13) Observe the OVERLOAD indicators on the tracking adapter and the spectrum analyzer and the LOCK indicator on the tracking adapter. If either of the OVERLOAD indicators lights repeatedly, the test should be repeated beginning at step 8 with the amplifier set on a higher RANGE scale. If the LOCK indicator extinguishes at any time the test should be repeated beginning at step 9.

14) When the engine speed reaches 8400 RPM, maintain this speed for approximately two minutes.

15) Accelerate the engine to the overspeed condition of 8650 RPM.

16) After approximately 10 seconds, press the STOP A button on the spectrum analyzer.

17) Shut down the engine.

18) Change the OPERATE/GROUND switch on the amplifier to GROUND.

19) Obtain the System Sensitivity setting for the amplifier RANGE scale from Table 8.

20) Change the CURSOR FREQUENCY TYPE switch on the spectrum analyzer to SINGLE.

21) Depress and HOLD the CURSOR AMPLITUDE REFERENCE switch on the spectrum analyzer in the SET R position, and raise or lower the GAIN switch until the value indicated in the REFERENCE LEVEL field of the display, shown in Figure 12, equals the System Sensitivity.

22) Depress or raise the GAIN control on the spectrum analyzer until the highest peak of the spectrum is close to but does not exceed the top grid line.

23) Press the CURSOR control to the left or right until the CURSOR POSITION field in the display shown in Figure 12 indicates the percentage of full-scale orders for the first spectral component shown in Table 9.

24) Adjust the CURSOR control in single steps to the left or right until the cursor dot is at the peak of the nearest spectral component.

25) Read the CURSOR AMPLITUDE field of the display shown in Figure 12 and log it on the Record Sheet.

26) Repeat steps 23, 24 and 25 for all of the components shown in Table 9.

27) If all the measured amplitudes are less than the corresponding maximum permissible amplitudes shown in Table 9, the gearbox may be passed and testing is complete. If the 75.4 N component exceeds 40 g, but is less than 50 g, the following additional steps are necessary to determine whether the gearbox may be passed.

28) Change the OPERATE/GROUND switch on the amplifier to OPERATE.

29) Warm up the engine and set the speed to 7150 RPM.

30) Repeat steps 10 to 26.

31) If the amplitude of the 75.4 N component is less than 40 g, the gearbox may be passed and testing is complete.

6. CALIBRATION OF INSTRUMENTS

6.1 Accelerometer

Periodic calibration of the sensitivity and frequency response of the accelerometer is required. Section 5.1 of Reference 2 describes the procedure for back-to-back calibration against a transfer standard. It is recommended that the calibration be performed at intervals of three months. The transfer standard itself should be calibrated every twelve months at a NATA-approved laboratory, such as the Government Aircraft Factory, or the National Measurement Laboratories.

6.2 Amplifier

Periodic calibration of the sensitivity and frequency response of the amplifier is also required. Sections 3.1, 3.3 and 3.4 of Reference 3 describe the procedures for calibrating the amplifier. It is recommended that this calibration be performed at intervals of six months.

6.3 Attenuator

The values of the resistance and capacitance in the attenuator may change slightly over a long period of time. If a reference signal is recorded at the start of each tape, or after a long interval between recordings, these changes for the most part will be incorporated in the value of the Reproduce Ratio.

However, the Reproduce Ratio will not compensate for changes in the time constant of the attenuator, upon which its high frequency performance depends. It is recommended that the procedure described in Appendix B for the selection of components for the attenuator be repeated at intervals of six months.

6.4 Tape Recorder

The performance of the tape recorder will be degraded over a period of time by the accumulation of dust particles and residual magnetism along the tape path. Before mounting each tape, the head, guide and capstan surfaces should be cleaned with a cotton swab slightly moistened with a recommended cleaning solution or Freon TF. After every 20 to 30 hours of operation, the heads and metallic parts of the tape path should be demagnetized with a head demagnetizer as shown in Reference 4. It is essential that the tape recorder be switched off before demagnetizing the above components.

The frequency response of the tape recorder depends very much on the specific type of magnetic tape used. Before a new type of tape is accepted for the recording of vibration signals, the frequency response of the tape recorder with the new tape MUST be measured according to the procedure described in Appendix C, and the matching of the accelerometer, amplifier and tape recorder verified as described in Appendix D.

The performance of the tape recorder may change slightly over a long period of time. If a reference signal is recorded at the start of each tape, or after a long interval between recordings, these changes for the most part will be incorporated in the Reproduce Ratio.

However, the Reproduce Ratio will not compensate for changes in the frequency response of the tape recorder. It is recommended that the frequency response be measured according to the procedure described in Appendix C and the matching of the accelerometer, amplifier and tape recorder verified as described in Appendix D at intervals of six months.

6.5 Tracking Adapter

It is recommended that the alignment procedure described in Section 5.1 of Reference 6 be performed at intervals of 12 months.

6.6 Spectrum Analyzer

It is recommended that the user adjustments described in Section 7 of Reference 5 be performed at intervals of 12 months.

The instrument acquired by CAC is fitted with Option 05, comprising a set of built-in testing routines which allow the performance of the digital circuits to be checked in the field. Instructions for using these routines are given in Reference 6. It is recommended that the tests be performed at intervals of six months.

7. CONCLUDING REMARKS

The test procedures described in this report have been in use at CAC for more than 18 months. During that time the equipment has proved highly reliable, with only one failure, which was traced to a loose plug inside the tracking adapter.

It is envisaged that the equipment will find many other applications in the field of engine vibration testing.

REFERENCES

1. Edwards, D.H., King, C.N. and Pavia, R.V., "Vibration Measurements of Accessory Angle Drive Gearboxes on Atar 09C Engines", Department of Defence, Aeronautical Research Laboratories, Mechanical Engineering Report 144, November 1974.

2. Sunstrand Data Control, Inc., "Model 815-Series Piezotron Accelerometers", September 1974.

3. Sunstrand Data Control, Inc., "Model 504E Dual Mode Amplifier", October 1976.

4. Sony Corporation, "Stereo Tapecorder TC-510-2 Owner's Instruction Manual".

5. Nicolet Scientific Corporation, "Instruction Manual for Model 444 Mini-Ubiquitous FFT Computing Spectrum Analyzer", 1977.

6. Nicolet Scientific Corporation, "Instruction Manual for Model 24C Spectrum Tracking Adapter with Automatic Filtering (Option 07)", 1975.

7. Commonwealth Aircraft Corporation, "Engineering Authorization No. 10040", May 1973.

APPENDIX A. DESIGN OF ATTENUATOR

Figure 13 shows the circuits of the attenuator and the electrical equivalent of the tape recorder input. The subscripts "a" and "i" denote "attenuator" and "input" respectively. At DC, the attenuation is given by:

$$\frac{V_o}{V_i} = \frac{R_a + R_i}{R_i} \tag{3}$$

If the attenuator is frequency compensated, C_a and C_i are related by:

$$R_a C_a = R_i C_i \tag{4}$$

The input impedance of the tape recorder is specified as 100 kΩ (Reference 4), but the individual values of R_i and C_i are not given. For this reason, R_a and C_a were determined experimentally using the procedure described in Appendix B.

Using that procedure, values of 3MΩ and 4.7 pF were determined for R_a and C_a respectively. The exact value of attenuation is determined implicitly in the calculation of the Reproduce Ratio in Section 4.3. The attenuator also compensates for the input cable capacitance.

APPENDIX B. SELECTION OF COMPONENTS FOR ATTENUATOR

1) Connect the signal generator, voltmeter, attenuator, tape recorder and oscilloscope as shown in Figure 14.

2) Release the L and R RECORD MODE buttons.

3) Set the SOURCE/TAPE select switch to SOURCE.

4) Set the other controls of the tape recorder as shown in Figures 9a to 9d and Table 4.

5) Adjust the signal generator output frequency to approximately 10 kHz.

6) Set the signal generator to sine-wave mode.

7) Adjust the signal generator output level until the voltmeter indicates 1 V RMS.

8) Adjust the value of the attenuator resistance until the left-hand VU meter indicates 100%.

9) Adjust the inner RECORD LEVEL control (channel R) on the tape recorder until the right-hand VU meter indicates 100%.

10) Adjust the oscilloscope until the traces from channels L and R are visible on the screen.

11) Set the signal generator to square-wave mode.

12) Adjust the signal generator output level until both VU meters indicate less than 100%.

13) Adjust the value of the attenuator capacitance until the oscilloscope traces from channels L and R exhibit the same rise time and overshoot.

14) Repeat steps 7 to 13 until constant values of resistance and capacitance are found.

APPENDIX C. MEASUREMENT OF FREQUENCY RESPONSE OF TAPE RECORDER

1) Connect the sweep oscillator, tape recorder, voltmeter and plotter as shown in Figure 15.

2) Depress the L and R RECORD MODE buttons.

3) Set the SOURCE/TAPE select switch to SOURCE.

4) Set the other controls of the tape recorder as shown in Figures 9a to 9d and Table 4.

5) Use the REWIND/FAST-FORWARD lever to move the tape to the required location as shown by the tape counter.

6) Place a sheet of linear-logarithmic graph paper similar to that used in Figures 16 and 17 on the plotter.

7) Set the sweep oscillator output frequency to 20 Hz and adjust the X-axis zero control on the plotter until the pen is positioned over the 20 Hz mark on the paper.

8) Set the sweep oscillator output frequency to 20 kHz and adjust the X-axis gain control on the plotter until the pen is positioned over the 20 kHz mark on the paper.

9) Repeat steps 7 and 8 until both positions are correctly set.

10) Set the sweep oscillator output frequency to approximately 10 kHz.

11) Adjust the sweep oscillator output level until the left-hand VU meter indicates approximately 100%.

12) Set the sweep oscillator output frequency to approximately 500 Hz.

13) Set the voltmeter range to 1 V RMS.

14) Push the FUNCTION selector and turn it clockwise to the RECORD position.

15) Change the SOURCE/TAPE select switch to TAPE.

16) Press the Y-axis zero button on the plotter and adjust the Y-axis zero control until the pen is positioned over the zero response ratio mark on the paper.

17) Release the Y-axis zero button on the plotter and adjust the Y-axis gain control until the pen is positioned over the unity response ratio mark on the paper.

18) Repeat steps 16 and 17 until both positions are correctly set.

19) Set the sweep oscillator output frequency to 20 hz.

20) Lower the plotter pen.

21) Slowly sweep the oscillator frequency from 20 hz to 20 kHz.

22) Raise the plotter pen.

23) Turn the FUNCTION selector counter-clockwise to the STOP position.

APPENDIX D. MATCHING THE ACCELEROMETER, AMPLIFIER AND TAPE RECORDER CHARACTERISTICS

The vibration components of interest in angle drive gearbox testing lie in the frequency range 2 to 14 kHz. To ensure accurate assessment of gearbox condition, the frequency response of the entire analysis system should be flat to within about ±5% over this range. The instruments which have the greatest influence on the response are the accelerometer, amplifier and tape recorder.

For on-line analysis, the tape recorder is not required. Table 11 shows that the response of a typical accelerometer and amplifier fitted with a matched 20 kHz filter is flat to within ±2% over the range 1 to 20 kHz. Therefore, for on-line analysis, fitting the special matched 20 kHz filter in the amplifier will give a frequency response adequate for vibration testing of the gearboxes.

For off-line analysis, with the 150 kHz filter fitted in the amplifier, the rising response characteristic of the accelerometer will tend to compensate for the fall in frequency response of the tape recorder above about 10 kHz. Table 12 shows that the response for the system of accelerometer, amplifier and tape recorder remains flat to within about ±5% over the range 2 to 14 kHz. Therefore, for recording and subsequent off-line analysis, the 150 kHz filter will give a frequency response adequate for vibration testing of the gearboxes.

From the figures given in the preceding paragraphs, it is clear that the frequency response of the system for on-line analysis is superior to that for recording and off-line analysis. Therefore it is recommended that on-line analysis be performed whenever possible.

APPENDIX I. CALCULATION OF SYSTEM SENSITIVITY

Tests on the tracking adapter have indicated that a sine-wave of approximately 300 mV RMS applied to the SIGNAL input is sufficient to cause the OVERLOAD indicator to be illuminated when the SIGNAL ATTENUATOR is set to 0 dB.

Since the amplifier produces a full-scale output of 1 V RMS (Reference 3), the SIGNAL ATTENUATOR should be set to 15 dB for on-line analysis. If the 100 g amplifier range is selected, then an acceleration of 100 g will produce 1V at the input to the tracking adapter. With the SIGNAL ATTENUATOR set to 15 dB, the output from the tracking adapter will be 178 mV, corresponding to a System Sensitivity of 1.78 mV/g, or 1.78-3 V/g as shown in Table 8. The System Sensitivities for the 50 and 200 g ranges may be calculated in a similar manner.

The LINE outputs of the tape recorder have a nominal full-scale of approximately 435 mV RMS (Reference 4). To avoid overloading the tracking adapter, the SIGNAL ATTENUATOR should be set to 10 dB for the analysis of recorded data. The System Sensitivities shown in Table 7 may be calculated in the manner already described.

Since the full-scale filtered output of the tracking adapter is approximately 300 mV, the spectrum analyzer SENSITIVITY should be set to 500 mV to prevent overloading.

Although the use of more sensitive settings on the tracking adapter and spectrum analyzer would improve the signal-to-noise ratio of the system, the number of possible switch combinations and the need for frequent resetting of the reference level on the spectrum analyzer would greatly increase the risk of errors.

APPENDIX F. CALCULATION OF ENGINE ORDERS

The Atar 09C engine has a two-pole tachogenerator operating at 0.50364 times engine speed to produce an electrical output at a frequency of 1.00728 times engine speed. During testing of the angle drive gearbox at CAC, engine speeds of 5600 RPM to 8650 RPM are used, corresponding to tachogenerator frequencies of approximately 96 to 145 Hz.

The following equation, adapted from Section 3.18 of Reference 6, relates the control settings of the tracking adapter to the maximum number of engine orders displayed on the spectrum analyzer.

$$O = \frac{PM}{2.56D} \tag{5}$$

where: O = maximum number of engine orders

P = number of tacho pulses per engine revolution

M = tracking adapter multiplier setting

D = tracking adapter divider setting.

In order for the filter in the tracking adapter to function, D must be set to 2 or greater, and to resolve the 92.6N vibration component, O must be greater than 92.6. P is equal to 1.00728. Rearranging Equation 5 gives

$$\frac{M}{D} > \frac{2.56\ O}{P} = 235.3 \tag{6}$$

For a D of 2, the only M which satisfies Equation 6 is 512, giving a full-scale range of 100.7 engine orders. No other M or D settings are suitable.

Table 14 summarizes the engine orders and percentage of full-scale orders rounded to the nearest 0.25% for the vibration components generated by the angle drive gearbox.

During testing at CAC, a 30-slot tone wheel is fitted to the engine shaft to drive the Rochar test house tachometer. While the higher tachogenerator frequency would improve the locking speed of the tracking adapter, the only suitable M and D settings would position the 92.6 N component at 98.75% of full-scale orders. It was considered that this was too close to the right-hand vertical axis to be examined conveniently.

TABLE 1. BIAS AND EQUALIZATION SETTINGS

Tape	Bias	Eq
Sony FeCr-5-275-EL	Normal	Fe-Cr
Scotch AV177	Low	Special

TABLE 2. TRANSDUCER SENSITIVITY SETTINGS
(CALIBRATED ARL MAY 1979)

Transducer	Serial Number	Sensitivity (mV/g)
Kistler 815A2	1369	10.00
	1371	10.02
	1382	10.33

TABLE 3. AMPLIFIER SETTINGS

Panel	Control	Setting
Front	Power	On
	Operate/Gnd	See Text
	Sensitivity	See Text
	Range	See Text
	Time Constant	Short
	Mode	Piezo
Rear	Filter	See Text

TABLE 4. TAPE RECORDER SETTINGS

Panel	Control	Position
Top	Tape Speed	19 cm/s (7½ ips)
	Speed Tuning	Centre
	Bias	See Text
	Equalization	See Text
	Rec Mode	See Text
Front	Mic Att	Not Critical
	Line/Mic	Line
	Limiter	Off
	Source/Tape	See Text
	Tape Counter	See Text
	Rec Level L	Fully Clockwise
	R	See Text
	VU meters	See Text
	Pause	Release
	Function Selector	See Text
	Rewind/FF	See Text
Right	Mode	L+R
	Speaker	On
	Level	Centre
Left	Power	On
	Low Filter	Off

TABLE 5. TRACKING ADAPTER SETTINGS

Control	Position
Power	On
Signal Attenuation	See Text
Filtered/Bypass	Filtered
Speed/Tach Rate	Speed
Pulses/Rev	01
Tach Level	Fully Counter-Clockwise
Multiplier	X512
Divider	02
Setup	Not Critical

TABLE 6. SPECTRUM ANALYZER SETTINGS

Panel	Control	Position
Front	Power	On
	Resolution	400 Line
	Number N	Cont
	Plotter	At Curs
	Mode	Peak
	Display	A
	Cursor Freq Type	See Text
	Reading	hz
	Cursor Ampl Units	V
	Ref	See Text
	Gain	See Text
	Scales Frequency	Lin.
	Amplitude	Lin.
	Sensitivity	500 mV
	Input Weighting	Off
	Test/AC/DC	AC
	Frequency Range	100,000
	Freq/Orders	Orders
	Trig Level	Not Critical
	Hold/Rel	Rel
	ID On/Off	On
	ID Number	Not Critical
Rear	Store Mode	Aux
	Annotation	Data
	Weighting Window	Hann

TABLE 7. SYSTEM SENSITIVITY FOR ANALYSIS OF RECORDED SIGNAL

Amplifier Range Scale (g/V)	System Sensitivity (V/g)
50	6.32-3
100	3.16-3
200	1.58-3
500	632.-6

TABLE 8. SYSTEM SENSITIVITY FOR ON-LINE ANALYSIS

Amplifier Range Scale (g/V)	System Sensitivity (V/g)
50	3.56-3
100	1.78-3
200	889.-6
500	356.-6

TABLE 9. MAXIMUM PERMISSIBLE VIBRATION
(REFERENCE 7)

Component	% of Full-Scale Orders (% Rounded)	Maximum Vibration (g RMS)
23.1 N	23.00	100
25.1 N	25.00	40
46.2 N	46.00	100
50.2 N	50.00	40
69.4 N	69.00	100
75.4 N	74.75	40 (See Text)
92.6 N	92.00	100

TABLE 10. FREQUENCY RESPONSE OF ACCELEROMETERS (CALIBRATED ARL MAY 1979)

Frequency (kHz)	Response Ratio	
	Accelerometer	
	SN 1369	SN 1371
1	1.00	1.00
2	1.00	1.01
5	1.00	1.02
10	1.03	1.05
11	1.04	1.06
12	1.05	1.06
13	1.06	1.08
14	1.08	1.10
15	1.09	1.12
16	1.11	1.13
17	1.17	1.20
18	1.17	1.20
19	1.21	1.18
20	1.27	1.30

TABLE 11. FREQUENCY RESPONSE OF TYPICAL ACCELEROMETER (SN 1096) AND AMPLIFIER WITH MATCHED 20 kHz FILTER

Frequency (kHz)	Response Ratio
1	1.00
2	1.00
5	1.00
8.6	.99
10	.97
12	1.00
15	.99
20	1.01

TABLE 12. FREQUENCY RESPONSE OF ACCELEROMETER, AMPLIFIER AND TAPE RECORDER WITH 150 kHz FILTER (CALIBRATED ARL MAY 1979)

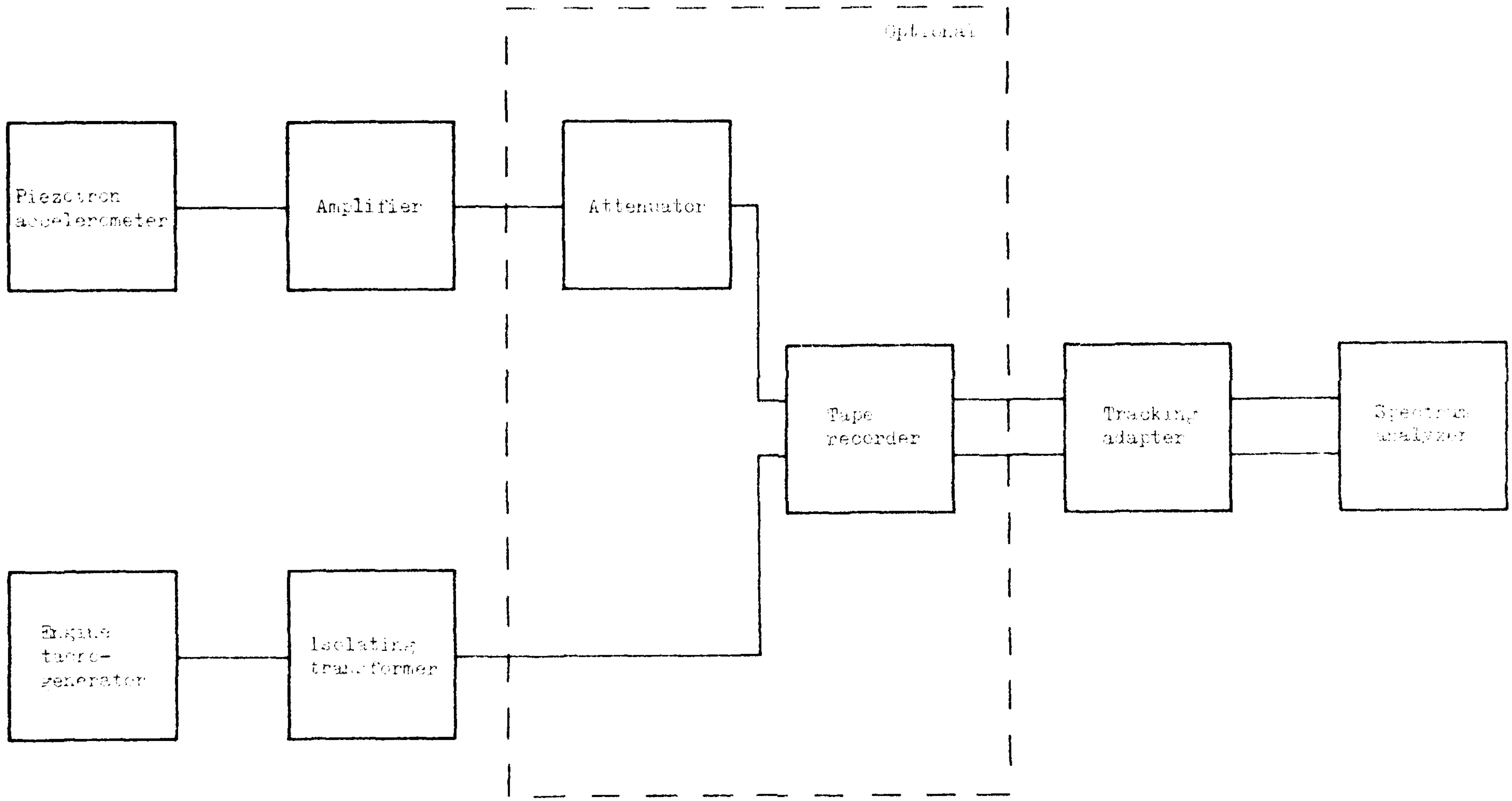
Frequency (kHz)	Response Ratio			
	Sony FeCr Tape		Scotch AV 177 Tape	
	Accelerometer		Accelerometer	
	SN 1369	SN 1371	SN 1369	SN 1371
2	1.06	1.06	.95	.96
5	1.04	1.06	.97	.98
10	1.04	1.06	.96	.98
11	1.05	1.07	.95	.97
12	1.03	1.04	.93	.94
13	1.01	1.03	.90	.92
14	.98	1.00	.86	.88

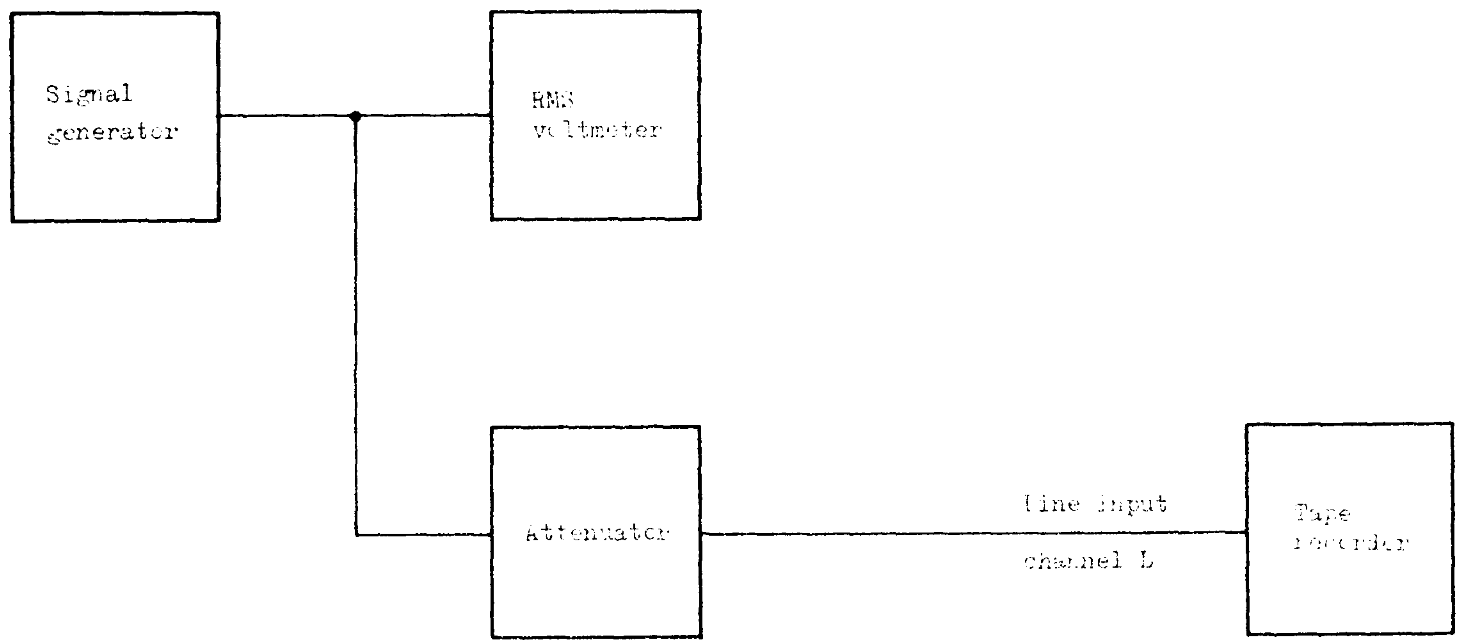
TABLE 13. FREQUENCY RESPONSE OF TAPE RECORDER (CALIBRATED ARL MAY 1979)

Frequency (kHz)	Response Ratio	
	Sony FeCr Tape	Scotch AV 177 Tape
2	1.06	.96
5	1.04	.97
10	1.01	.94
11	1.01	.92
12	.98	.89
13	.95	.85
14	.91	.80

TABLE 14. PERCENTAGE OF FULL-SCALE ORDERS

Component	Engine Orders	% Full-Scale Orders	% Full-Scale Orders (Rounded)
23.1 N	23.149	22.98	23.00
25.1 N	25.133	24.95	25.00
46.2 N	46.298	45.96	46.00
50.2 N	50.267	49.90	50.00
69.4 N	69.447	68.95	69.00
75.4 N	75.400	74.86	74.75
92.6 N	92.596	91.93	92.00


Piezotron accelerometer
Amplifier
Attenuator
Optional
Tape recorder
Tracking adapter
Spectrum analyzer
Engine tacho-generator
Isolating transformer


Signal generator
RMS voltmeter
Attenuator
Line input
channel L
Tape recorder

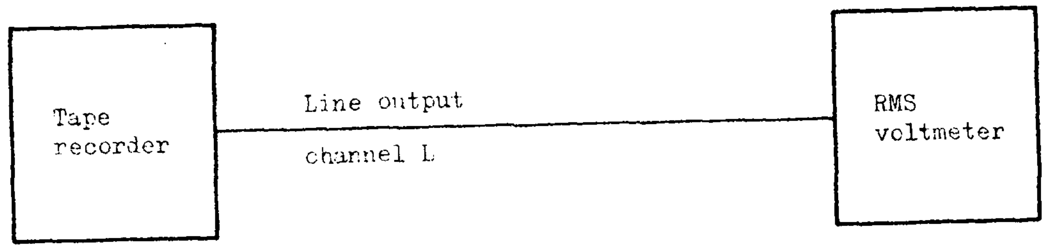


FIG. [illegible] CONNECTIONS FOR REPRODUCING A REFERENCE SIGNAL

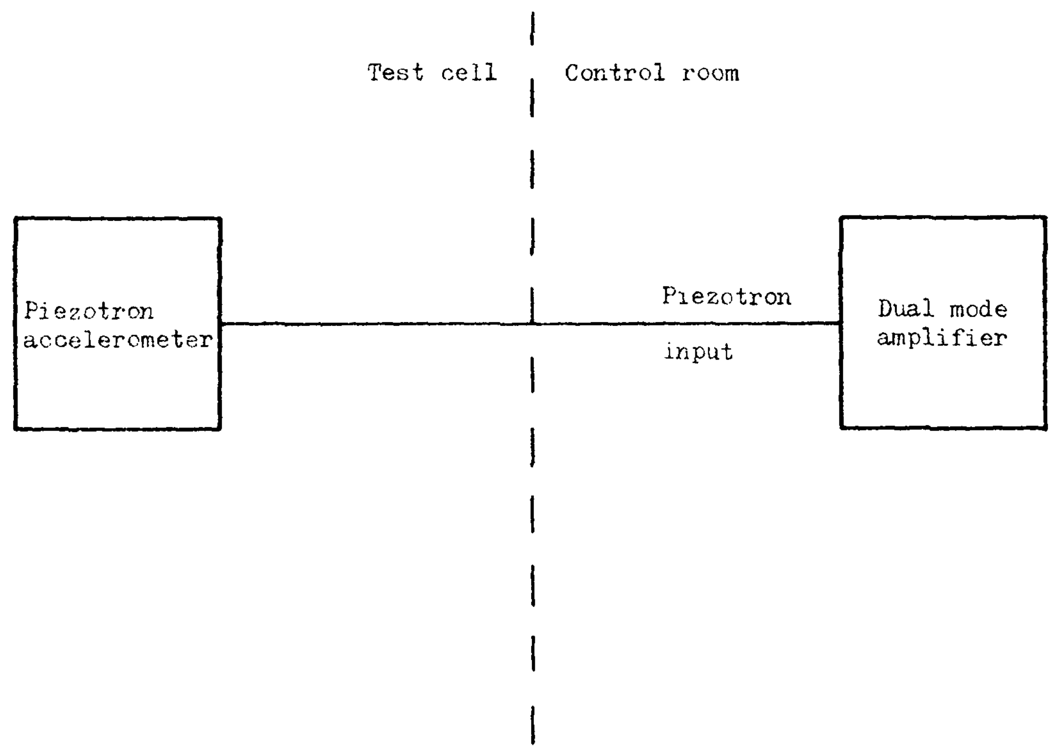


FIG.4 CONNECTION OF ACCELEROMETER AND AMPLIFIER

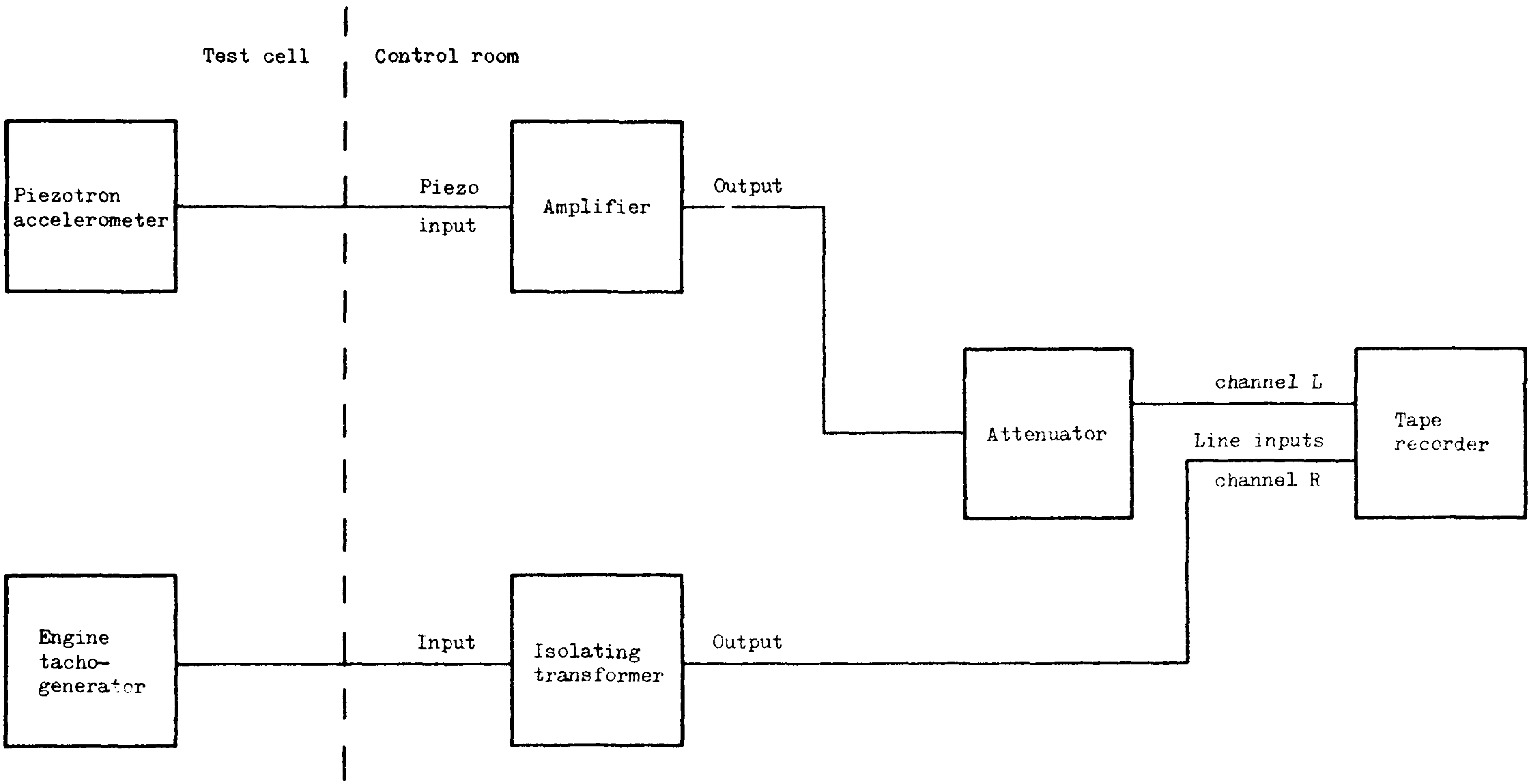
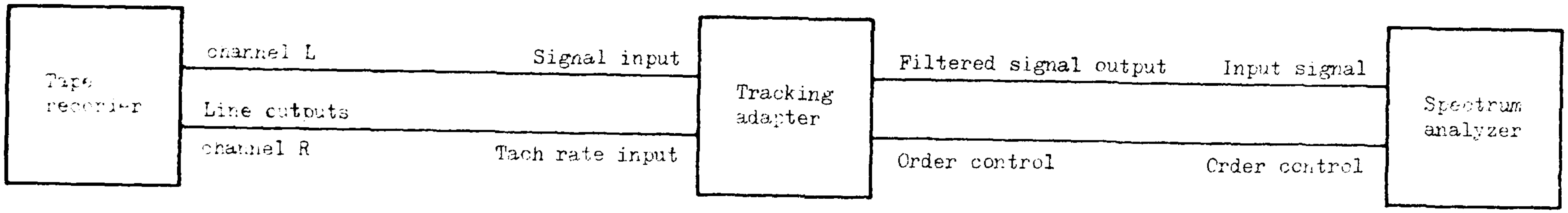


FIG.[illegible] CONNECTIONS FOR RECORDING A VIBRATION SIGNAL



[illegible] CONNECTIONS FOR REPRODUCING A VIBRATION SIGNAL

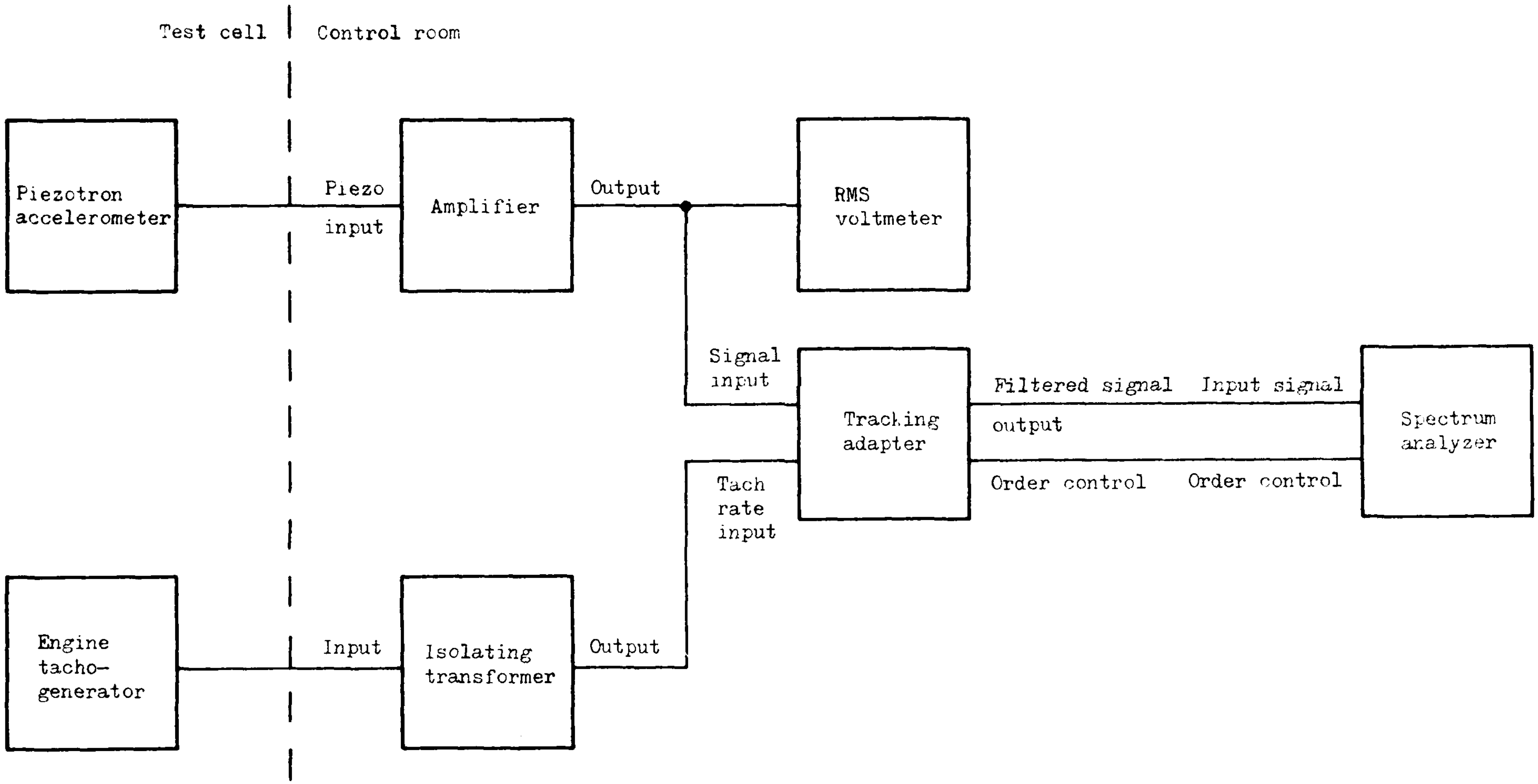


FIG.7 CONNECTIONS FOR ON-LINE ANALYSIS

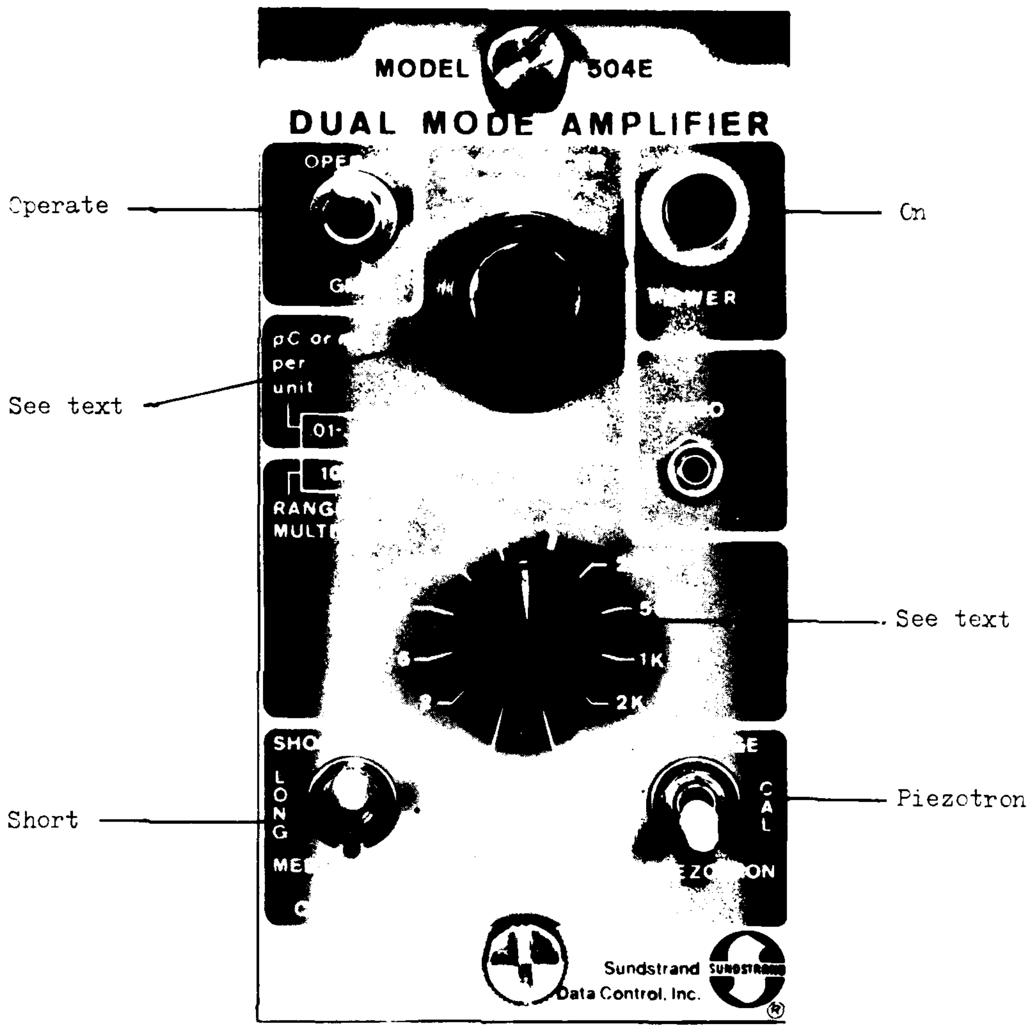


FIG.8 AMPLIFIER SETTINGS

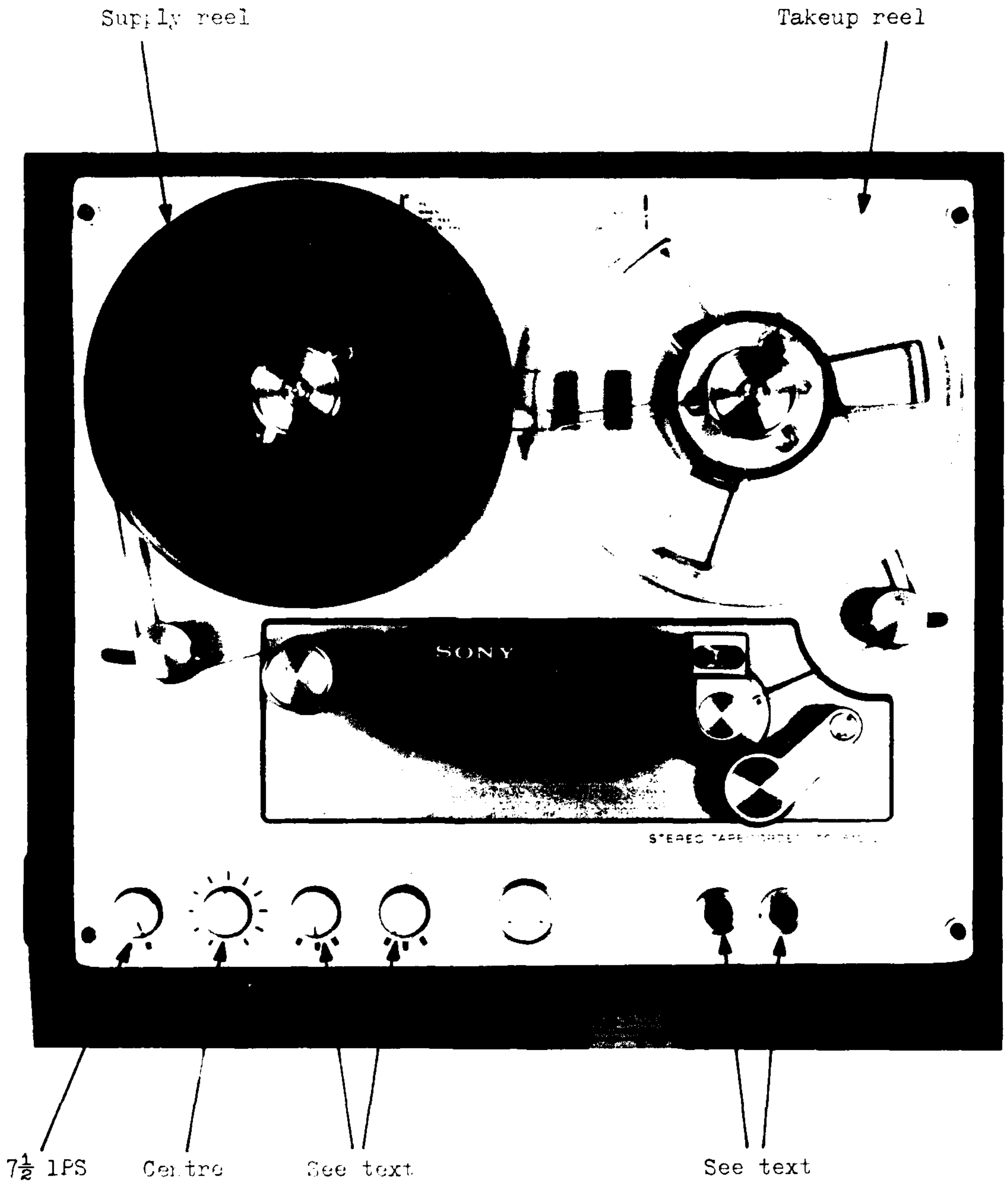


FIG.9(a) TAPE RECORDER SETTINGS (TOP PANEL)

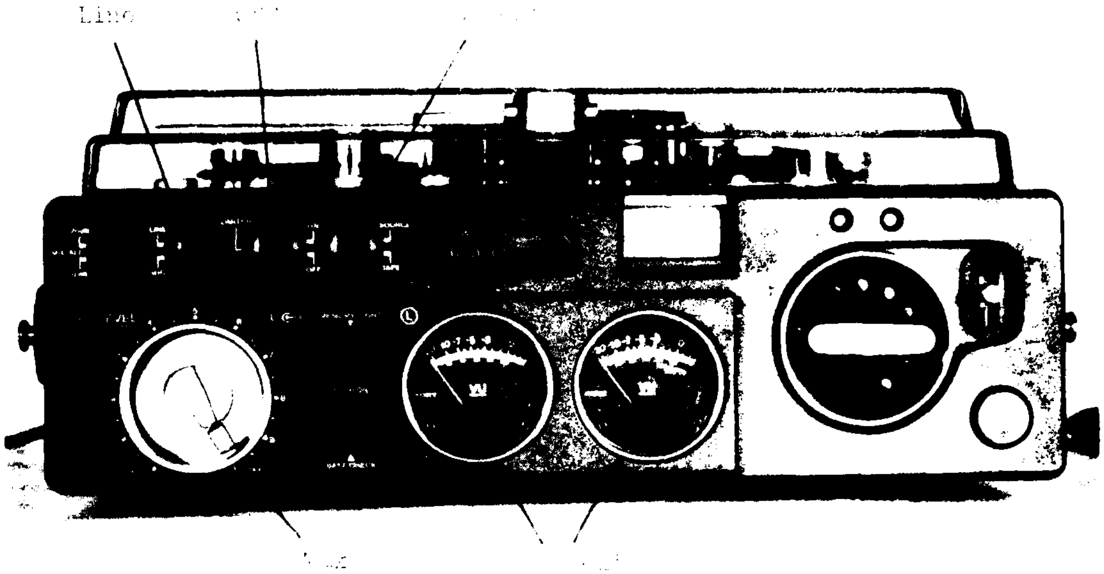

Line

FIG.9([illegible]

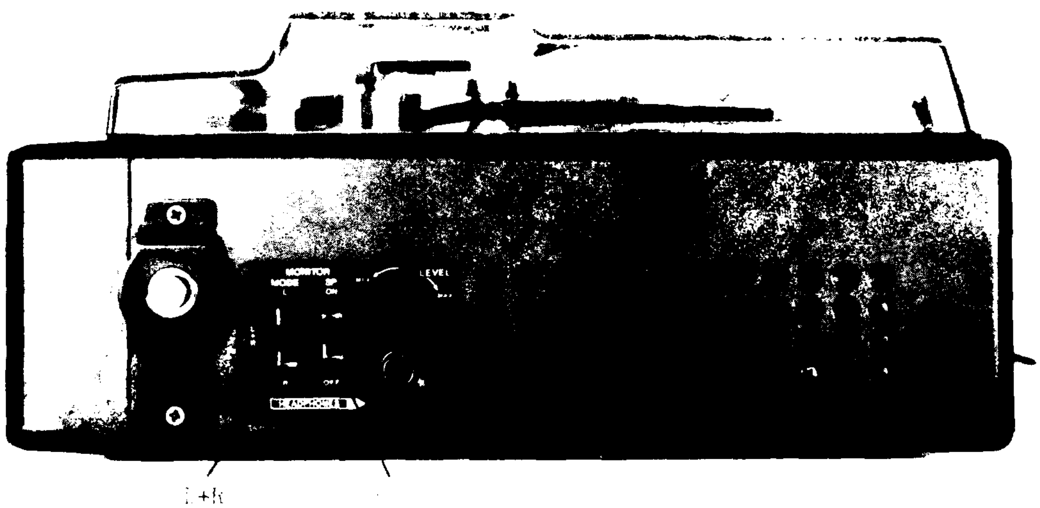
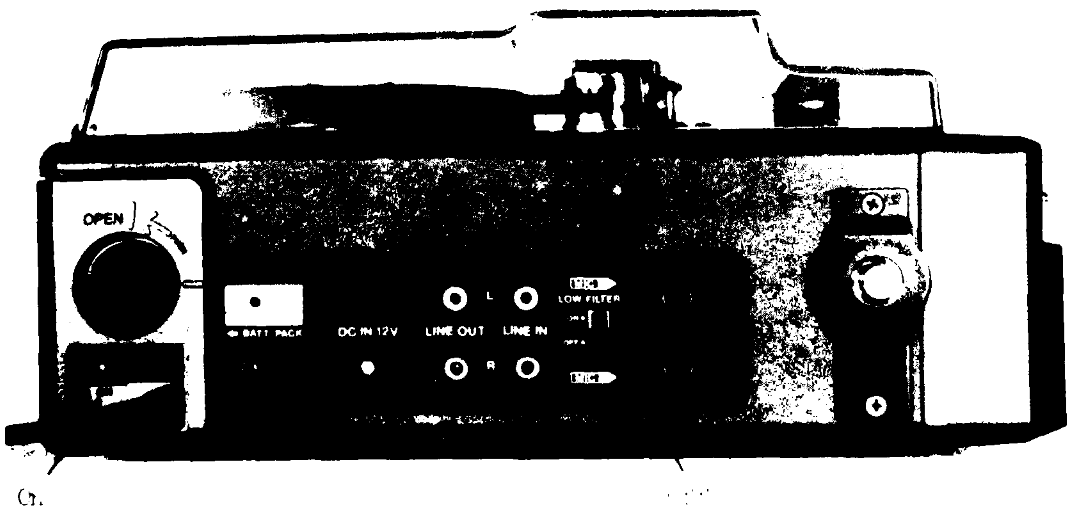

MONITOR
MODE
SP
ON
OFF
LEVEL
L+R

FIG.9([illegible]


OPEN
BATT PACK
DC IN 12V
L
LINE OUT
LINE IN
R
LOW FILTER
Ch.

[illegible]

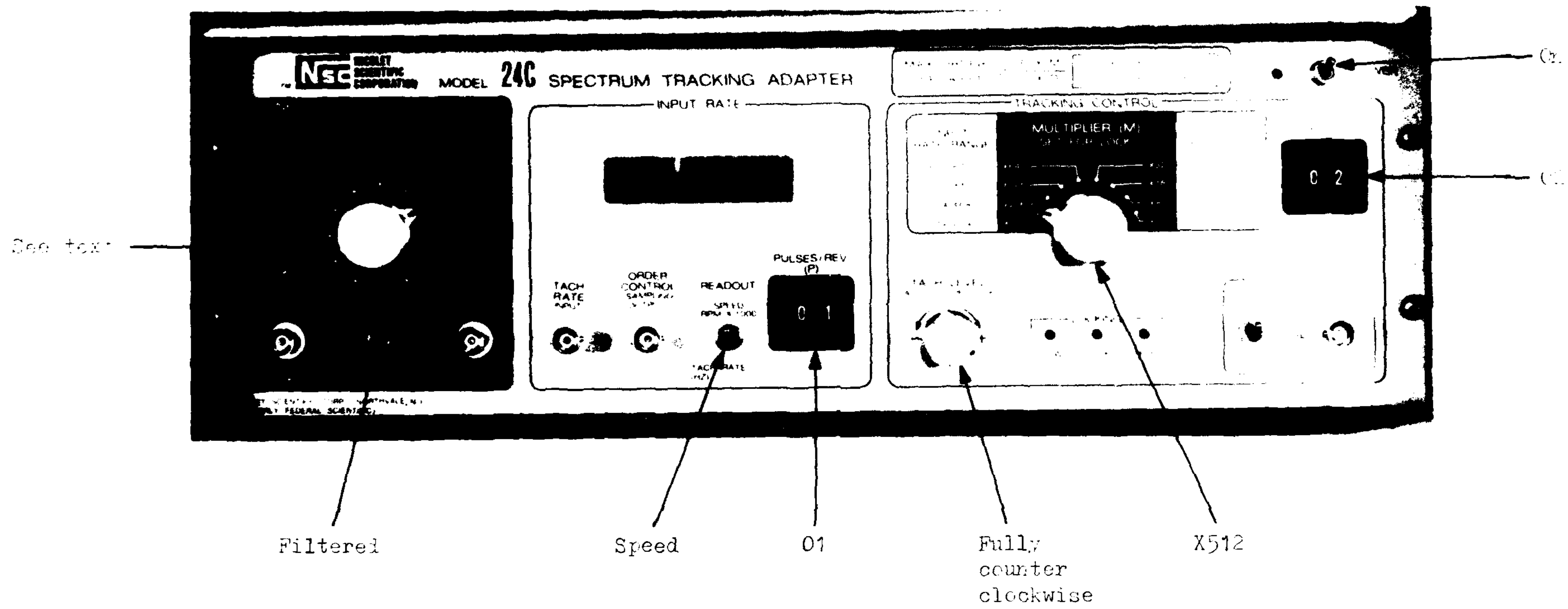


FIG.10 TRACKING ADAPTER SETTINGS

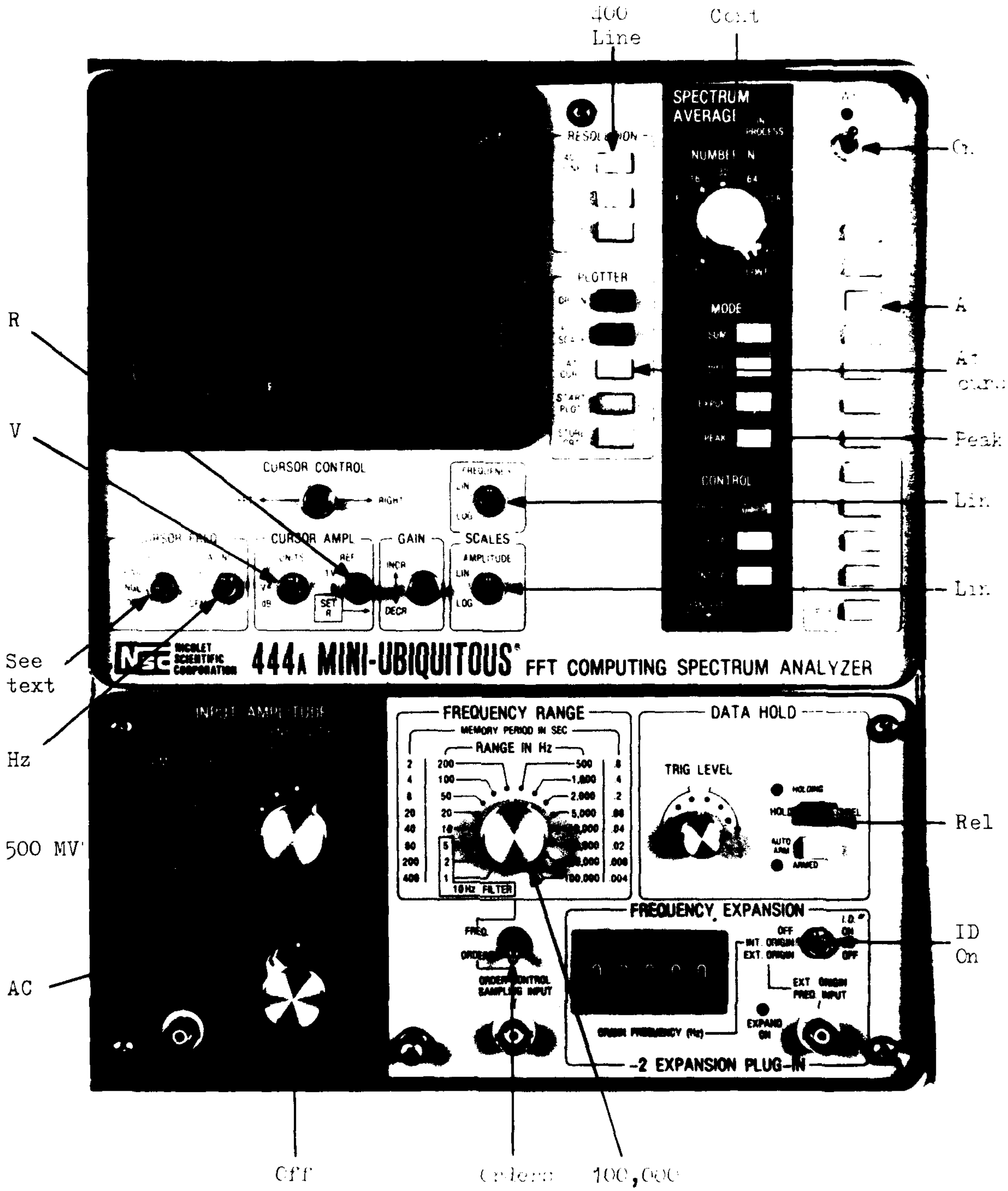


FIG.11(a) SPECTRUM ANALYZER SETTINGS (FRONT PANEL)

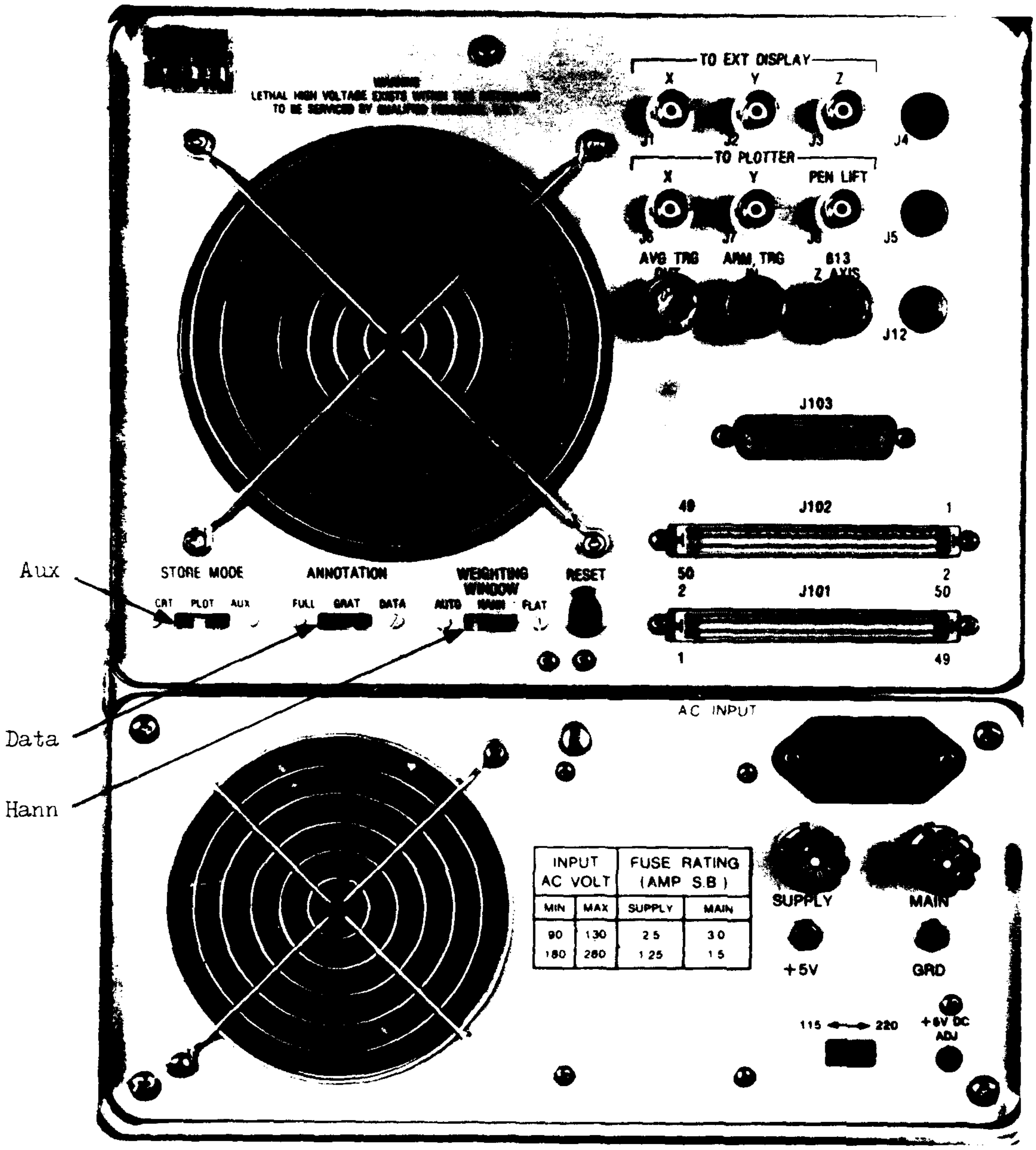


FIG.11([illegible]) SPECTRUM ANALYZER SETTINGS (REAR PANEL)

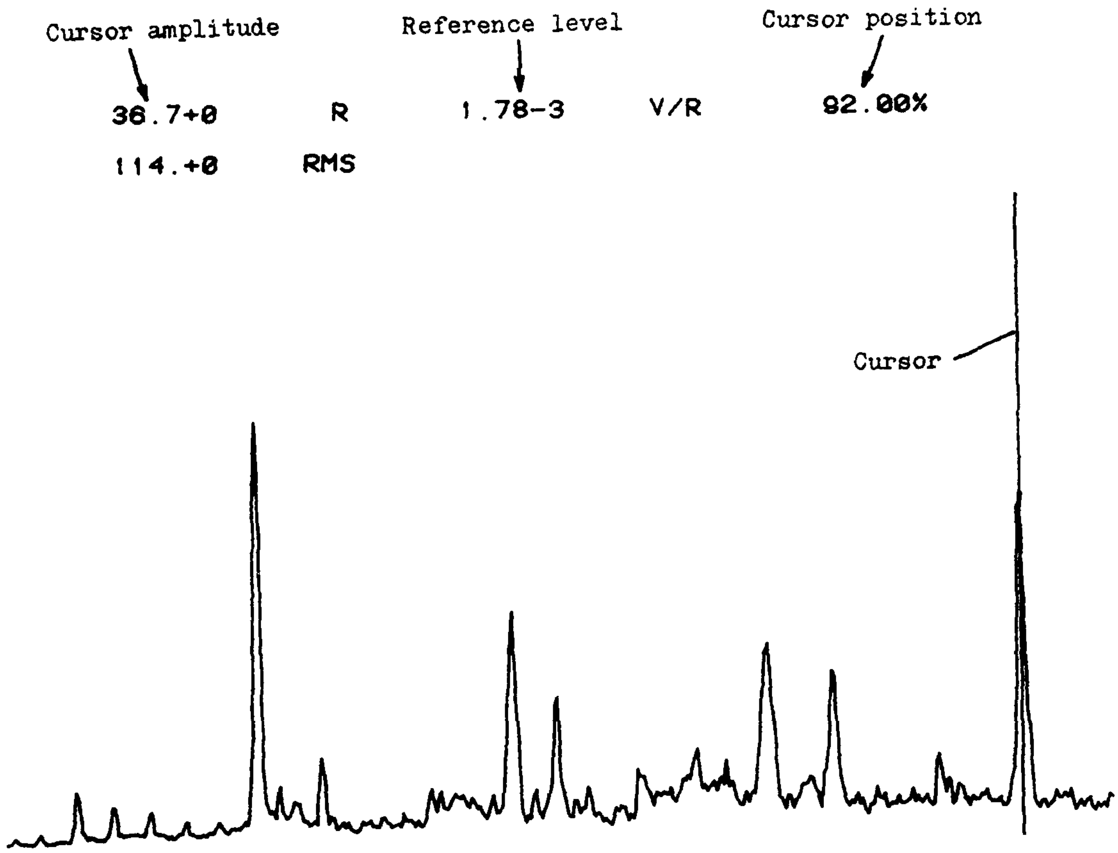


FIG.12 SPECTRUM ANALYZER DISPLAY

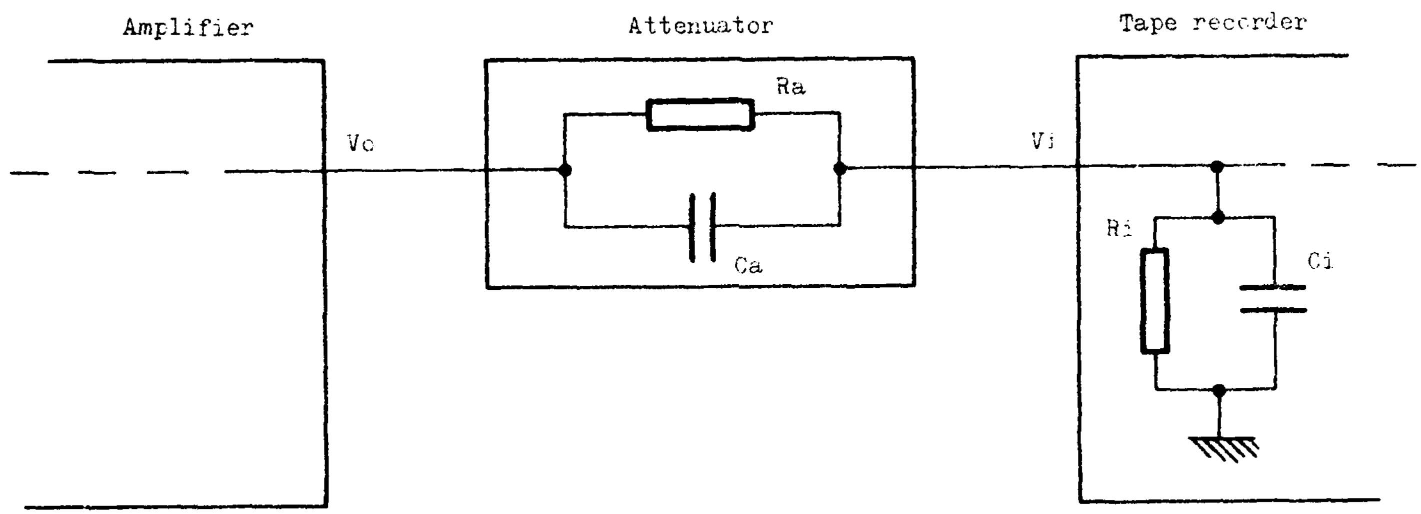


FIG.1 - EQUIVALENT CIRCUIT OF ATTENUATOR AND TAPE RECORDER

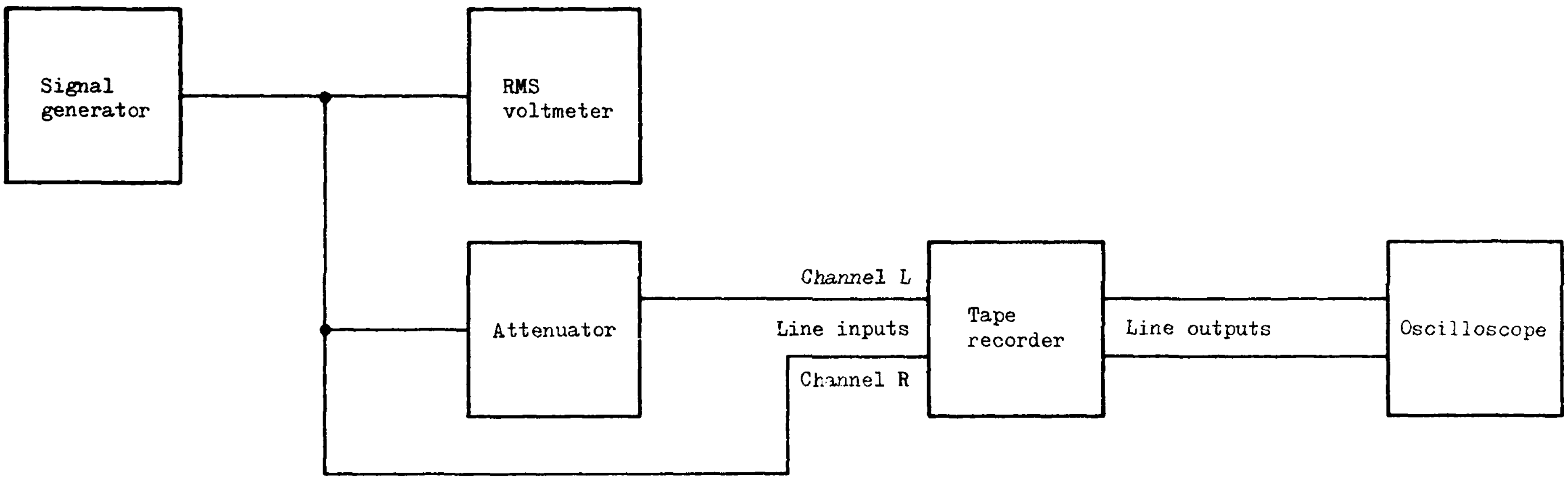


FIG.14 CONNECTIONS FOR SELECTION OF COMPONENTS FOR ATTENUATOR

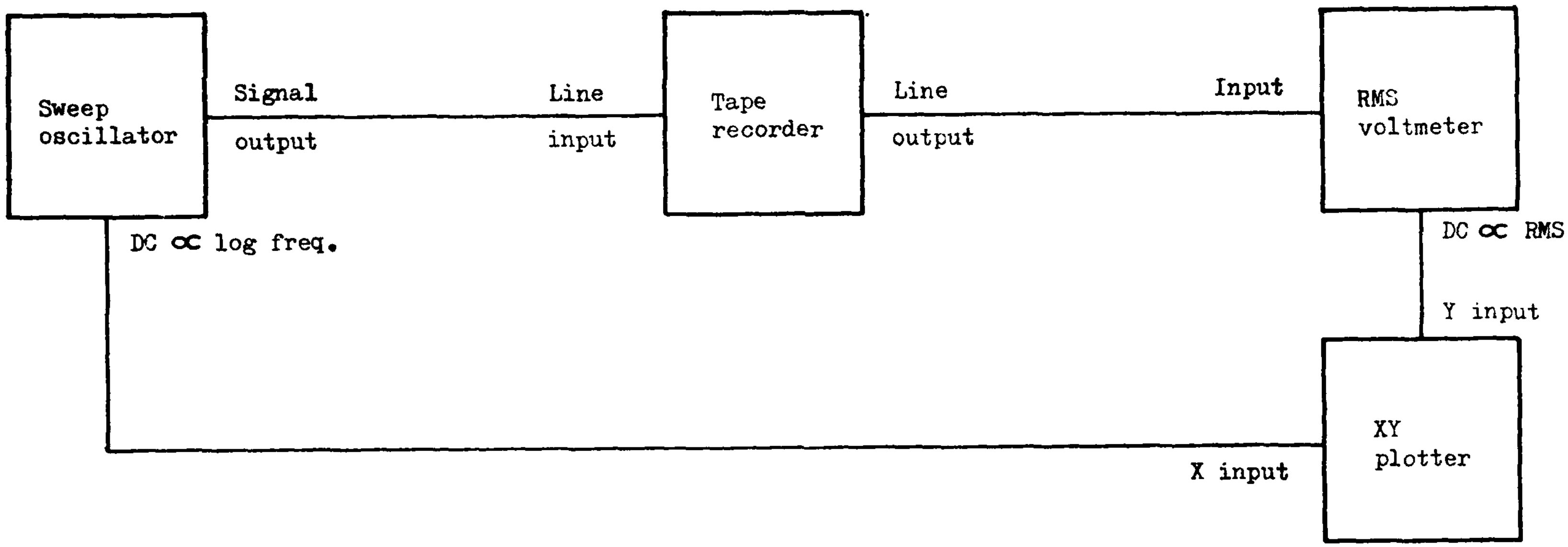


FIG.15 CONNECTIONS FOR MEASURING FREQUENCY RESPONSE OF TAPE RECORDER

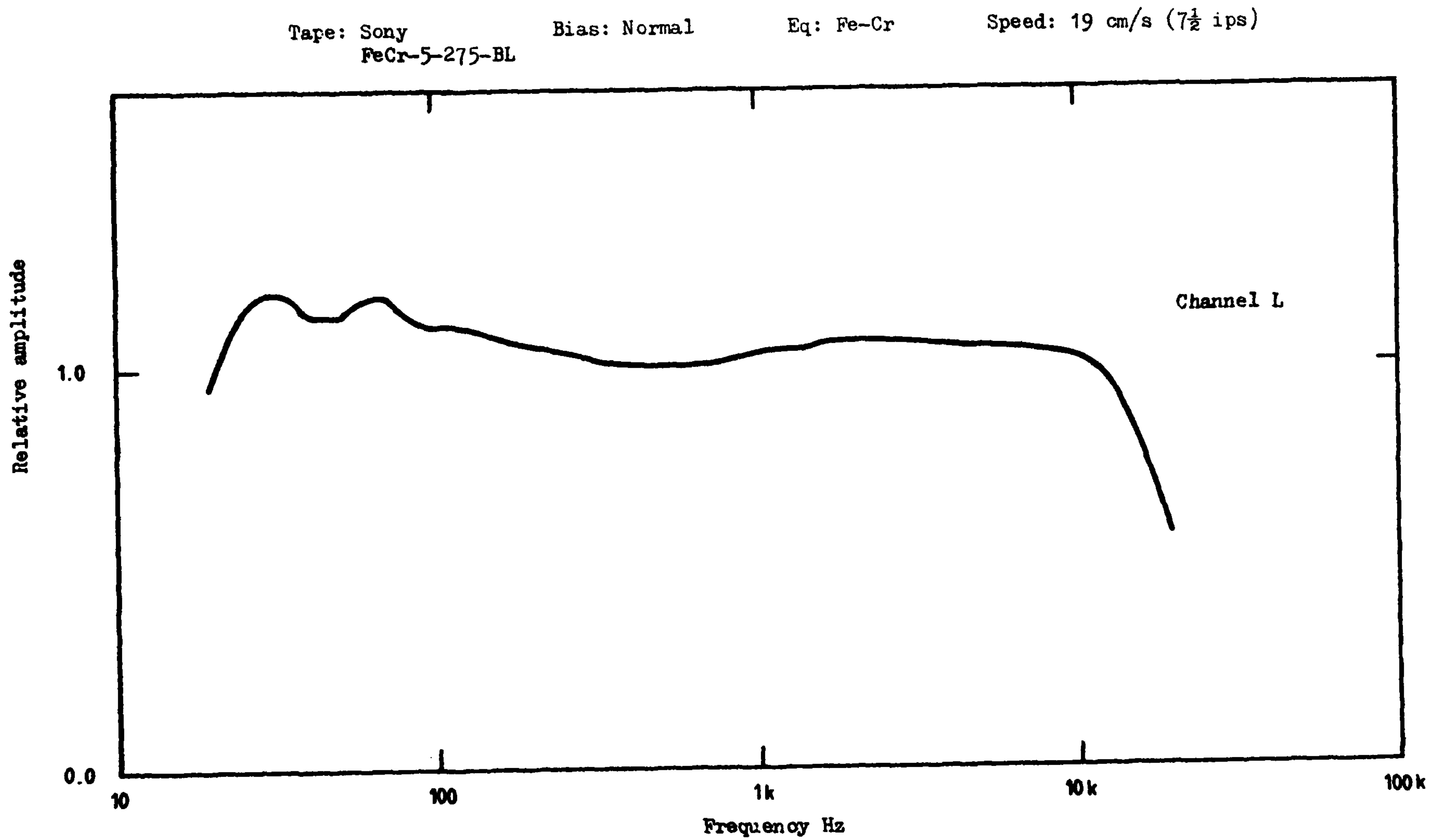


FIG.16 FREQUENCY RESPONSE OF SONY TC-510-2 RECORDER

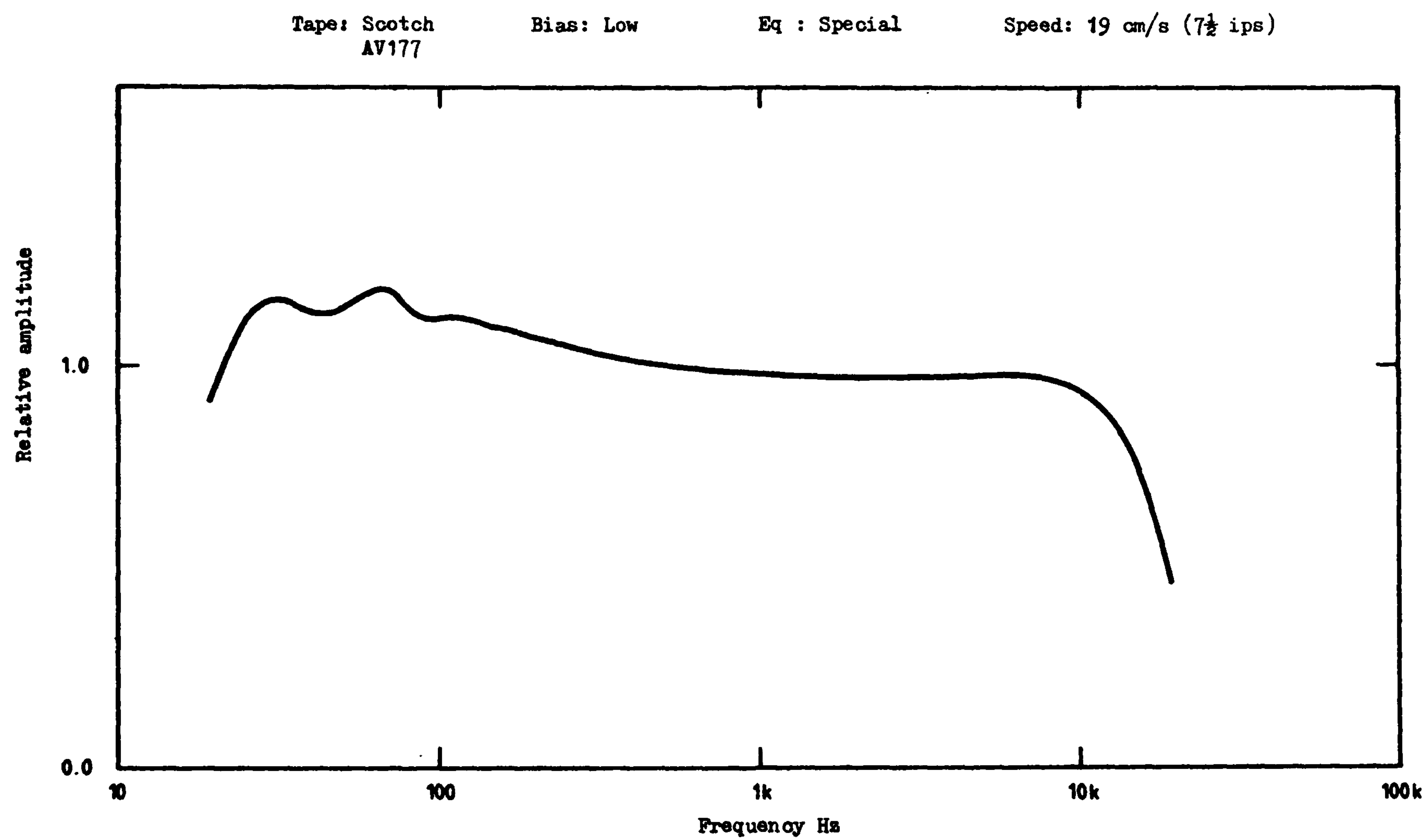


FIG.17 FREQUENCY RESPONSE OF SONY TC-510-2 RECORDER

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